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ASSESSMENT OF THE SAFETY OF TRANSPORTATION, DISTRIBUTION AND STORAGE OF METHANOL FUELS

SUMMARY REPORT

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For.

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1. BACKGROUND

The Government of Canada is currently supporting a number of investigations and vehicle demonstrations of the use of methanol as a transport fuel. The fuel types investigated range from the use of 100% methanol as a replacement for diesel fuel in compression-ignition and spark-ignition bus and truck engines, to the use of methanol as an additive to gasoline - with and without the addition of cosolvents such as ethanol or butyl alcohol.

Alberta and Ontario exempt the methanol portion of motor vehicle fuels from provincial road fuel taxes. Consideration of similar tax forgiveness at the federal government level has been recommended.

In the U.S., methanol has been identified by the Department of Energy and the Environmental Protection Agency as the most plausible of the alternative fuels for use in the U.S. The Alternative Motor Fuel Act of 1988 established demonstrations and studies of alternative fuels with particular reference to methanol, compressed natural gas and electric vehicles.

There is already substantial use of methanol in gasoline blends in the U.S. and increasing support of large-scale demonstrations of methanol as a fuel for automobiles (Ford automobiles on test in California) and for city buses (demonstrations in Los Angeles, San Francisco, Seattle, Jacksonville and many more planned). These activities are proceeding, despite the current partial dependence on imports of Canadian and other foreign-sourced methanol, and a low level of experience on the health and safety implications of expanded methanol use.

Since Canada is a large market for U.S. automobiles, gasoline and diesel engines (Canada has no domestic production of diesel engines for highway use) and is a world-scale producer and exporter of methanol, it

is important that the health and safety implications of methanol use be investigated before methanol engines are introduced here on a commercial scale.

Methanol production in Canada in 1987 totalled 11.4% of the world production of 18.5 million tonnes, but Canada's consumption was only 1.4% of world consumption (see Exhibit 1). The three Canadian producers will be major suppliers of methanol to the U.S. fuel market and information on methanol fuel safety will be important to the development of that export potential and to the adoption of methanol as a vehicle fuel in Canada.

Canada has already developed a significant market for propane and natural gas in the transportation sector and a body of experience, information and regulations which control the safety of these fuels in storage, during distribution and in conversion, repair, garaging and refuelling of propane and compressed nautral gas vehicles. A corresponding body of information has still to be developed on methanol fuel safety, since the present experience with methanol is essentially limited to its distribution and use within the chemical industry and trials as vehicle fuel.

The perceived wisdom that methanol safety is not significantly different from that of gasoline may be correct in vehicles, but may not be so in the transportation, storage and distribution sectors. The climate and transportation infrastructure in Canada is different from that in Europe and the U.S. and special problems related to the Canadian environment need identification.

This report is a summary of a larger report entitled "Assessment of the Safety of Transportation, Distribution and Storage of Methanol Fuels".

Exhibit 1

Perspective on Canadian Methanol Production and Demand

	Production	Demand
	Tonnes/Annum 1987	
International		
Canada	2,100,000	250,000*
USA	3,160,000	4,572,000
World	18,500,000	18,000,000
Canada		
Alberta Gas Chemicals (Alta.)	850,000	
Celanese (Alta.)	850,000	
Ocelot (B.C.)	400,000	
	2,100,000	

Natural gas required for current methanol production is equivalent to 4% of natural gas sales.

Methanol production in energy terms is equivalent to:
1.6% of oil refinery output of petroleum products
4.1% of gasoline sales and 2.8% of gasoline and diesel sales
11% of LPG (Liquefied Petroleum Gas) production
16% of LPG use in Canada

* Rest is export

Scope and Objectives

The assessment is limited to the safety of methanol fuels and a comparison with gasoline and diesel in bulk transportation (ship/barge, rail and pipeline modes), distribution (by tank truck and at service stations, storage (at bulk terminals and service stations). Vehicle repair is also included, but vehicle operation is not, since this has been reported on previously.

The scope of the safety assessment includes the frequency and magnitude of methanol spills ("loss of containment"), the frequency and effects of fires and explosions and notes on the toxicity of the fuel.

The objective is to provide information to facilitate the development of the legislation, equipment, training and emergency response capabilities.

2. METHANOL AS A TRANSPORT FUEL

Reasons for Adoption of Methanol Fuel

A variety of energy sources and engines has been considered for highway transportation but engine production technology, resource availability and fuel cost considerations led to the adoption of gasoline used in spark-ignition ("Otto cycle) engines and diesel fuel in compression ignition ("diesel cycle") engines as the dominant combinations. The oil price increases and supply concerns of 1973 and 1979 stimulated commercial use of CNG and propane, as they could be used in slightly modified current technology engines.

The development of the methanol fuel market where methanol is used as a minor component of gasoline blends (3-5% by volume frequently with the concurrent use of a similar volume of a cosolvent such as butyl or methyl alcohol) was also rapid. The market for high methanol-content fuels has been limited, however, by incompatibility of methanol fuel with a number of alloys and plastics used in the gasoline system and by the requirement to develop new technology for the use of methanol fuels in diesel engines. The slow development of the methanol fuel market may not prevent that fuel from becoming the dominant alternative to diesel and gasoline, since a number of factors favour its adoption.

The key factor affecting the future adoption of methanol, CNG or propane is the anticipated benefit to public health and reduced crop damage which will accompany the reduction in the level of ozone, carbon monoxide and particulates in the environment. Production of ozone is related in a complex way to the irradiation of unburned hydrocarbon and nitrogen oxides (NOx) in the air. Over 60 communities in the U.S. do not comply with the current ozone requirement of the National Ambient Air Quality Standard (0.12 parts per million in air hourly average once per year). Similar levels of non-compliance exist with NOx and carbon monoxide.

The urban air quality in a number of Canadian cities is inadequate and can be traced in large part to vehicle emissions: 20% of the NOx released in Canada, 24% of the hydrocarbon emissions and 45% of the carbon monoxide are attributed to automobile emissions. Transport Canada is responsible for the emission standards of new vehicles under the Motor Vehicle Safety Act; the development and enforcement of in-use regulations is a provincial government responsibility.

Exhibit 2 illustrates the level of reduction of vehicle emissions which may be achieved using methanol. Other factors affecting the future adoption of methanol are summarized in Exhibit 3 which also provides information on CNG and propane as alternatives to gasoline. As with methanol, CNG and propane can be used in vehicles dedicated entirely to the alternative fuels or adapted to operate on either the alternative or the conventional fuel. The advantage of the recently developed methanol flexible-fuel vehicle is that it can operate on a mixture of methanol and gasoline in any proportion, whereas the gaseous fuels are used in dual fuel systems where the engine operates on either the alternative or the conventional petroleum fuel. Use of the conventional fuel in flexible or dual fuel vehicles reduces the environmental benefit of using the alternative fuel, prevents optimization of the engine, and retains both the safety advantages and disadvantages of each of the fuels.

Exhibit 2

Standards and Typical Vehicle Emissions

	CO	NOx	Exhaust Hydrocarbon	Particulates (grams/brake horse power hour)
	grams/mile			
AUTOMOBILES AND VEHICLES WITH EMISSION CONTROL SYSTEM				
Standard 1988+ maximum	3.4	1.0	2.0	
M100	2.2	0.6	0.15	
M100 as % gasoline in same vehicle	45	90	40	
HEAVY DUTY VEHICLE BUS WITHOUT EMISSION CONTROL SYSTEM				
Standard 1991 Bus (1994 Truck)	15.5	5.0	1.3	0.1
M100	2.55	3.0	0.6	0.02*
M100 as % diesel in same engine type	45	30	50	1

* Particulates in diesel engine exceed 1991 EPA standard by factor of 2-5 until particulate traps are used

Exhibit 3

Factors Affecting Adoption of Alternative Fuels

FACTORS AFFECTING ADOPTION		METHANOL RANK	METHANOL DESCRIPTION	PROPANE RANK	PROPANE DESCRIPTION	CNG RANK	CNG DESCRIPTION
VEHICLE RELATED	Engine availability - autos	+	Flexible fuel vehicle can use either gasoline or methanol blends	+	Minor modification of gasoline engine	+	Minor modification of gasoline engine
	- trucks, buses	+/-	Low availability of heavy duty engines but several potential suppliers	+/-	Conversion of diesel is complex, engine and kits not yet widely available	+/-	Conversion of diesel is complex and engine kits not yet available
	Vehicle conversion capability	+	Manufacturers interested and no conversion industry is likely to develop	+	Many shops capable of conversions but limited range available from manufacturers	+	Conversions available
	Vehicle conversion cost	-	$300 premium for autos, $1700 for diesel truck, bus	-	$700 conversion cost	-	$2600-3000 conversion cost, offset by $500 federal grant
FUEL RELATED	Ease of refuelling	+	Same as gasoline because liquid	+	Similar to gasoline but pressure system	-	Slower than gasoline, more complex (high pressure system)
	Resource availability	+	Based on surplus gas	+	Surplus propane available	+	Large surplus available
	Local fuel availability	+/-	Not yet distributed but no problem	+	Available at over 4000 locations	+/-	130-140 stations in urban centres
	Fuel cost (annual) for vehicle	-	Needs twice fuel tank volume of gasoline	+	Cost savings up to 40% available	+	Cost savings up to 50% available
PERFORMANCE RELATED	Range	-	Better than CNG	+	Typically 80+% of gasoline range (dual-fuel systems overcome this)	-	Typically less than 50% of gasoline (dual-fuel systems overcome this)
	Vehicle performance (acceleration)	+	Superior to gasoline	+	Equivalent to gasoline	-	Somewhat less than gasoline
	Vehicle carrying capacity	+	Essentially unchanged from gasoline	+/-	Added volume of propane tank occasionally a disadvantage	-	Large increase in volume and weight of storage tanks limits acceptance
	Exhaust emissions	+	Cleaner burning than gasoline and diesel	+	Cleaner burning than gasoline and diesel	+	Cleaner burning than gasoline and diesel
SAFETY RELATED	Fire safety	+	As safe as gasoline	-	Somewhat less safe than gasoline	+	As safe as gasoline
	Toxicity	-	Similar to gasoline	+	Essentially non-toxic	+	Essentially non-toxic

KEY: + Positive factor for conversion decisions
- Negative factor for conversion decisions
Methanol is M100 or M85

3. FACTORS AFFECTING THE SAFETY OF METHANOL

Distribution Infrastructure

The conventional fuel system is based on the long-distance transportation of crude oil by ocean tanker and/or pipeline to refineries located close to markets from which gasoline, diesel fuel and other refined products are distributed - most frequently by road tanker direct to service stations or short pipeline/road tanker combinations through bulk terminals, and less often by barge or rail tanker.

Movements of the more volatile and hazardous gasoline and diesel fuel are therefore limited. In contrast, current and proposed future manufacture of methanol is favoured economically when close to the gas resource. Vehicle methanol is transported over long distances by combinations of ocean tanker, barge, rail and road tanker, although the feasibility of pipeline movements in crude oil and gas liquids has been demonstrated in Canada.

The low energy content of methanol relative to petroleum products (see Exhibit 4) requires that higher volumes of methanol must be transported. Since petroleum product movements and storage systems are most frequently designed to meet vessel and tanker capacity regulation, the frequency of vessel and tanker movements and the number of storage tanks must be increased. The high efficiency of methanol in engines compared to gasoline reduces the requirement to below that which might be expected on an energy density basis, but overall the replacement of gasoline and diesel fuel by methanol will increase the frequency of spills by a factor between 1.8 (gasoline replacement) and 2.3 (diesel replacement), or a factor of 2 if gasoline and diesel fuel are replaced in proportion to the volumes used in Canada in 1987.

Exhibit 4

Volumetric Factors Affecting Transportation of Methanol

	Light Crude Oil	Gasoline	Diesel	Methanol M100	Methanol M85
Energy content relative to gasoline, %	111	100	112	49	57
Volume of fuel/unit energy relative to gasoline %	90	100	90	204	176
Volume required in vehicle relative to gasoline %	N/A	100	130	180	168
Volume required in vehicle relative to diesel %	N/A	128	100	230	215

Methanol Properties Related to Safety and Handling

The key properties critical to the safe storage and transfer of methanol are discussed below in the context of their contribution to spills, the ignition of spills, the propagation of fires and explosions, and toxic effect.

Factors Affecting the Frequency and Size of Spills

As noted above, the effect of the two-fold increase in the volume of methanol required in vehicles increases the potential for spills compared to gasoline and diesel fuel.

Methanol is corrosive to aluminum, magnesium, copper, zinc, lead and to alloys such as brass used in fuel system fittings, and to terneplate used in the production of most gasoline and diesel vehicle fuel tanks. Gasoline and diesel have no effect upon these metals. Anhydrous methanol is not corrosive to mild steel, but addition of only 0.5% water induces corrosion. Many plastics and elastomers used in vehicles, tanks and in fuel hoses swell or crack after repeated exposure to methanol. The methanol distribution system must therefore be designed with selected methanol-tolerant materials and storage facilities to avoid water pick-up. Thus, aboveground storage tanks of mild steel are acceptable if water pick-up is avoided or special methanol-resistant fibreglass tanks are used. Methanol-resistant plastics such as polyethylene, polypropylene, acetates and fluorinated elastomers are preferred.

In the period of transition to the use of methanol fuel, it is certain that the existing distribution system and maintenance practices will be used and a higher frequency of spills due to corrosion and/or material failures is certain. These will not be present in dedicated methanol systems.

Where methanol is stored underground, the precautions taken against corrosion will need to be as stringent as with gasoline where a significant tank replacement program is being undertaken in view of the frequency of leaks from corroded tanks and piping.

In gasoline distribution it is recognized that 0.4-0.6% of the liquid volume is lost as vapour to the atmosphere as gasoline is moved from the refinery to the consumer through the intermediate stages of storage, transportation and fuel dispensing. The volume lost through vents, tank manholes and at vehicle tank inlets is dependent on the vapour pressure of gasoline, fuel temperature and the agitation and speed at which the product is pumped. The lower vapour pressure of M100 and diesel will reduce vapour losses compared to gasoline by at least a

factor of 2, but losses with M85 will be comparable to gasoline.

Factors Affecting the Frequency and Severity of Methanol and Gasoline Fires

As shown in Exhibit 5, methanol is less volatile than gasoline. The evaporation rate is lower (lower vapour pressure, higher heat of vapourization), and it has a higher flash point than gasoline. Both are defined as highly inflammable, having a flash point below 21°C. The likelihood of ignition is therefore similar where experience indicates that about 65% of major spills at service stations lead to ignition. A methanol vapour cloud at optimum air-fuel ratio will more readily ignite than gasoline, which has a lower minimum ignition energy than methanol. The lower explosion limit for methanol is higher than for gasoline but the range is wider. A methanol flame has a much lower maximum intensity of radiation (lower heat of combustion).

The consequences of this mix of mostly favourable and some unfavourable factors have been determined using a well-documented risk assessment methodology developed by the Industrial Safety Branch of TNO in The Netherlands. The results, given in Exhibit 6, show that with similar spill volumes the incidence of fatalities within the burning liquid pool will be the same (100% fatalities to persons within the burning pool area) for gasoline, M100 and M85, but the damage and fatality rate within the area exposed to the radiant heat from the pool fire will be much lower for methanol than for gasoline; M85 occupies an intermediate position. The reduction in damage and fatalities due to radiation would appear to more than affect the increased frequency of fuel transfers and volume of methanol used and indicate that M100 will be a safer commodity in a fire than M85 and gasolines with lower methanol content.

Exhibit 5

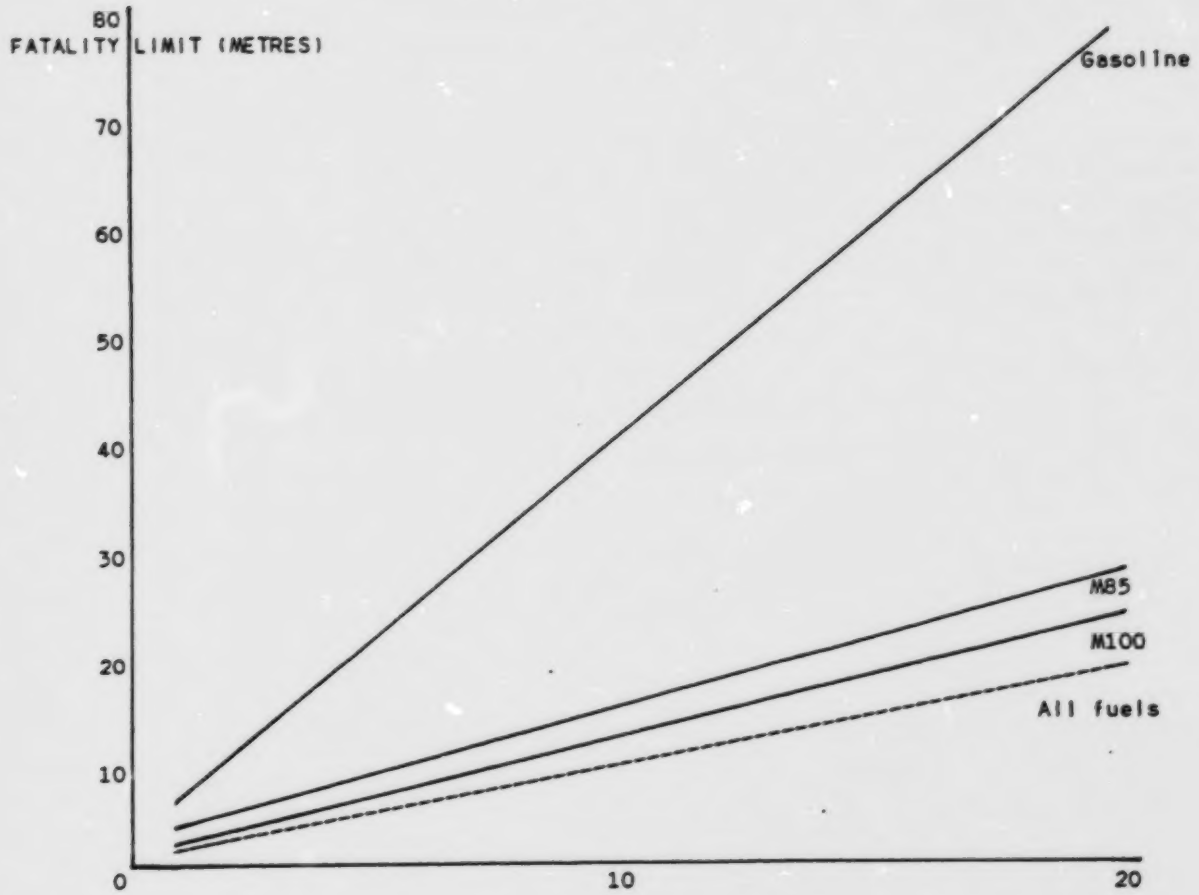
Fire-Related Properties of Methanol and Petroleum Fuels

	M100	M85	Gasoline	Diesel
Liquid density at 15°C (g/litre)	800	745	735	820-860
Boiling point °C	64.5	30-225	30-200	100-380
Flash Point °C	10	-43	-43	52
Auto-ignition temperature °C	385-480	222-480	222-425	22-315
Minimum energy for ignition in air MJ	0.14	0.14	0.24	0.3*
Exposure limits (% volume in air)	6.7-36.5	2-34	1.4-7.6	0.7-5.0
Vapour pressure kg/cm2 at 38°C	0.32	0.32	0.6-0.8	low
Heat of vapourization MJ/kg	1.1	0.98	0.3-0.34	0.3
Heat of combustion MJ/kg	19.6	23.2	43.5	42-43
Heat capacity of liquid MJ/kg,k	2.408	2.376	2.194	-

* Estimated

Exhibit 6

Fatality and Damage Distances for Methanol & Gasoline Pool Fires



Key: ———— 1% fatality distance

———— 100% fatality

Key Factors Affecting Fire-Fighting

The low visibility of the methanol flame presents a major problem to fire-fighters engaging a M100 fire. The low odour and radiant heat, despite the visibility of the liquid pool (compare propane and CNG) increase the probability that a fire-fighter may enter the fire. Addition of gasolines to the 15% volume level increases luminosity, but aromatic components are required to provide luminosity throughout the burn. The problem has yet to be solved as an increase in the aromatic content of fuels is undesirable in view of the carcinogenity of benzene and the high photo-activity of xylenes which contribute to the ozone burden of urban environments.

A further problem with methanol fire-fighting arises from the wide concentration levels of methanol in air which support combustion. Spills of methanol can lead to vapour accumulation in garages, drains and trenches which may be ignited by a flame, spark or other source of ignition. In confined spaces the fire may be accompanied by an explosion. Gasoline, in contrast, ignites at lower concentrations in air than methanol, but at concentrations above 7% the mixture will not support combustion and the fire and explosion hazard is therefore short-lived. The vapour space above methanol in a fixed roof storage tank or a vehicle tank contains methanol vapour within the flammable concentration range; this is not so with gasoline. Consequently, the practice in the methanol industry is to provide flame arresters in the tank vents and they may also be advisable in large vehicle tanks to reduce the fire and explosion hazard during vehicle refuelling and at vehicle accidents.

Another factor is the flammability of methanol-water solutions down to 25% methanol which requires that somewhat different fire-fighting practices be used in methanol fires than with petroleum fuels.

Toxicity of Methanol

Methanol, gasoline and diesel fuel are all toxic materials and ingestion, prolonged skin contact and inhalation of vapours create serious problems above certain threshold levels. See Exhibit 7. Ingestion of gasoline and diesel fuel occurs principally through siphoning of the fuels, but because these fuels have distinctive odour, are unpalatable and will be regurgitated if swallowed, the incidence of fatalities from ingestion is small (but positive). Although small quantities of methanol are ingested daily in fruits, vegetables and alcoholic beverages, ingestion of as little as 6ml may lead to symptoms of poisoning 12-48 hours later such as visual disturbances, abdominal pain, nausea and vomiting. Doses in the range of 100-250 can be lethal, although doses as low as 33ml have been lethal. Antidotes can be effective if applied in time.

Methanol could be ingested through fuel siphoning, drinking when mistaken for water or ethyl alcohol, or in water contaminated by an underground spill from a methanol storage tank. The low odour, low taste and absence of colour of methanol increases the ingestion hazard relative to gasoline and diesel and this issue must be resolved before large volumes of M100 are made available. The gasoline content of M85 is expected to sharply reduce the possibility of ingestion. Other measures could be the addition of parts per million of odourants (e.g. mercaptans similar to those added to natural gas and LPG), dyes and bitter-tasting materials similar to those used in the past to denature cooking alcohol.

Use of gasoline as a solvent and frequent contact with liquid gasoline at refuelling stations is to be avoided as prolonged skin exposure can cause dermatitis and skin blistering. Similar exposure to liquid methanol is more hazardous as methanol can be absorbed through the skin and is only slowly metabolized so that toxic effects can be compounded by repeated excessive exposures to the point where toxicity

Exhibit 7

Health Hazard Exposures for Methanol and Gasoline

	Gasoline	M100
Vapour Inhalation		
Short-term exposure level(STEL) ppm in air	500	250
Threshold limit value (TLV) ppm in air	300	200
Ingestion of Liquid		
Minimum lethal level of ingestion, ml	Not retained	30

STEL measured over 15 minutes
TLV measured over 8 hours

effects are possible. It is considered likely, but not proven, that M85 would be at least as hazardous as M100, because the gasoline content could accelerate methanol adsorption by defatting the exposed skin tissue.

Inhalation of fuel vapour is a potential hazard to drivers (vehicle exhaust, evaporative and refuelling emissions) to fuel industry employees and to those engaged in spill clean-up and fire-fighting. The effect of the materials is a function of the concentration of the fuel in air, and the duration of the exposure.

The short-term (15 minute) exposure level (STEL) for gasoline has been established by national health and safety authorities at 500 parts per million in air and the threshold limit value (TVL) at 300 ppm considered a safe level of exposure over an 8-hour work day. The low levels have been set to provide protection, not only against the effect of gasoline hydrocarbons on the respiratory tract and nervous system, but also against the particularly toxic and cumulative effects of benzene which may be present at up to 15% levels in gasolines. Although diesel fuel vapours are toxic, the low volatility of the fuel, except in fire, reduces the possible exposure.

Methanol vapour is toxic when high concentrations are inhaled. The vapours are life-threatening at concentrations above 25,000ppm in air and toxic effects are noted at 3,000ppm. The STEL has been set at 250ppm and the TVL at 200ppm to provide a wide margin of safety in the workplace. Concentrations above these levels are unlikely to be encountered except in unventilated mechanics' pits where dense vapours may accumulate and in cases of equipment failure. The low short-term exposure level (STEL) is a guideline for fire-fighters and spill decontamination squads who should use self-contained breathing apparatus if ventilation or water spray cannot reduce the concentration. The risk to the public from methanol vapour exposure in vehicle operation or refuelling is negligible. The toxicity of M85 vapour has not been established and work should be undertaken to ensure that there are no synergistic effects between the methanol and gasoline components.

5. INCIDENT DATA

Major Spills of Methanol and Gasoline

Environment Canada maintains a national database on spills in excess of 100kg of fuels and chemicals which may affect the environment. Exhibit 8 provides an analysis of the location, frequency and average volume of spill recorded in the 568 gasoline and 22 methanol spills recorded by Environment Canada in the period 1982-6. Comparison of the data for methanol and gasoline is compromised by the fact that the methanol data reflect the production, storage and transportation of methanol for chemical uses and export rather than for domestic vehicle fuel purposes, and the low volume of methanol involved in comparison with gasoline. The differences in the location of spills are expected to disappear when vehicle fuel becomes a dominant use for methanol.

The causes of spills were similar in the case of gasoline and methanol (Exhibit 9) involving truck overturns, collisions, leaks from piping and tanks, overfilling of tanks and malfunction of valves and fittings. These were occasioned in both cases by human error, material failure, weather and road conditions.

The effects of spills in the domains of methanol fuel storage, transportation and distribution are investigated in the following section.

Exhibit 8

Frequency of Major Spills of Gasoline and Methanol in Transportation, Distribution and Storage

		Frequency % Spills in Sector	Average Volume/Spill (cubic-metres)	
GASOLINE				
STATIONARY SOURCE				
Service station	HIGHEST	35.0	9.8	
Bulk storage	HIGH	19.0	190 0	
Other storage	MEDIUM	9.5	2.7	
Refinery	LOW	0.2	6.8	
TRANSPORT OF FUEL				
Tank truck	HIGH	20.5	12.1	
Other truck	LOW	2.1	1.6	
Train	LOW	1.8	13.6	
Pipeline	LOW	1.1	7.0	
Major pipeline	LOW	0.2	2420.0	(1 in 1985)
Marine	LOW	0.7	12.1	
Inland barge, tanker	LOW	1.2	14.8	
Other water	LOW	0.7	54.5	
METHANOL				
STATIONARY SOURCE				
Storage		4.5	31.2	
Refinery		4.5	16.4	
Chemical plant		4.5	36.0	
TRANSPORT OF FUEL				
Tank truck		50.0	10.5	
Train		22.5	18.7	
Pipeline		4.5	1.3	
Water craft		4.5	9.8	

Source: Environment Canada 1982-6
568 gasoline & 22 methanol spills recorded

Exhibit 9

Fuel Spills in Canada 1982-86: Causes and Reasons

GASOLINE		METHANOL	
RANK	CAUSE	RANK	CAUSE
1	Tank leak	1	Truck overturn
2	Overflow	2	Derailment
3	Pipe leak	3	Valve, fittings
4	Valve, fittings	3	Collision
5	Truck overturn	5	Discharge
6	Discharge	5	Other accident
7	Unknown	5	Pipe leak
8	Other accident	5	Tank leak
9	Collision	5	Overflow
10	Container leak	5	Other
11	Derailment		
12	Sinking		
13	Grounding		
13	Crash		
13	Other		
	REASON		REASON
1	Human error	1	Unknown
2	Unknown	2	Human error
3	Corrosion	3	ice frost
4	Equipment failure	3	Material failure
5	Material failure	3	Other
6	ice frost	6	Storm, flood
7	Vandalism	6	Road condition
8	Other	6	Overstress
9	Gasket, join	6	Earthquake
10	Damage by equipment		
10	Road condition		
12	Overstress		
13	Storm, flood		
14	Intentional discharge		
15	Subsidence		
15	Weld + seam failure		
17	Power failure		
17	Fire, explosion		
17	Earthquake		

6. SAFETY AT SERVICE STATIONS, BULK STORAGE TERMINALS AND GARAGES

Perspective

Since use of methanol as M100 or M85 as a vehicle fuel is experimental at the moment, only forecasts can be made of the safety hazards associated with the widespread use of the fuel. The forecasting methods used are based upon the interpretation of extensive existing data on gasoline safety in the light of the different volumes of methanol that will be used and the properties previously described. The comparison can be made at the judgmental level and through risk assessment calculations which incorporate "fault tree" analysis (equipment and human failures), data on the size and dispersion of spills, the frequency of ignition in spills, and knowledge of the casualty and damage effects from pool fires, heat radiation and explosions. Inclusion of site characteristics and data on population and structures adjacent to the actual or typical incident sites can be used to convert the effects data to casualty and damage forecasts. Both techniques were used in the present study.

The present investigation did not include analysis of vehicle incidents, except those involved in the transportation of fuels.

Service stations are the most frequently cited sources of gasoline spills (35%), and fires due to gasoline account for about 40% of all fires at service stations. In Canada in the period 1980 to early 1987 the average annual rate of reported incidents at public and private service stations totalled 115 - about one for each 113,000 vehicles in service in the year and one for every 233 million litres of gasoline sold - an excellent record.

45% of the incidents reported were leaks from underground storage tanks, but this has been reduced since 1984 through an aggressive tank replacement program.

Of the aboveground leaks reported some 10% resulted in fires, 4% in explosions and 4.5% in casualties. Assessment of the relative risk of casualties from fires involving the same throughput of M100, M85 and gasoline at stations with underground fuel storage is given in Exhibit 10. Even after allowance is made for the higher volume of methanol that will be required, it is concluded that the potential for casualties and damage from radiant heat are significantly reduced with M100 and M85 and in particular to persons and property outside the immediate refuelling area. This has an important bearing on the location of methanol refuelling facilities in urban communities and public acceptance of this alternative fuel.

The risk to fire-fighters may be compounded by the low visibility of the methanol fire and steps must be taken to minimize employee contact with liquid methanol. Accordingly it is recommended that:

- current work on means to improve the luminosity of M100 be continued
- means be developed to detect flames from M100
- instructional material for station staff and firefighters be prepared and training initiated shortly before a community adopts methanol fuel
- tests be conducted and a survey made of the safety of methanol storage tanks and designs to minimize fire and explosion hazards.

Bulk Storage Terminals

Bulk storage incidents account for 28% of the reported gasoline spills in Canada, but only 10% of the methanol spills; this suggests that the equipment and practices in the chemical industry may be more stringent than those in the petroleum industry and should not be relaxed in the conversion of depots to handle fuel methanol.

Exhibit 10

Maximum Distance and Effect of Fire Incidents

	Spill Volume	Frequency of Occurrence/Year	CASUALTY AND DAMAGE DISTANCES (METRES) 100% Fatality (In Pool)		1% Fatality (Radiation)
Escape from hose at refuelling	1.25 litres/sec	0.05	Gasoline	1	5
			M100	1	1.5
			M85	1	1.7
Tank truck failure (internal failure or impact)	2.5 litres/sec	0.13×10^{-7}	Gasoline	9	35
			M100	9	12
			M85	9	14
Tank truck failure (fire) Aluminum tank (ALUMINUM NOT USED FOR METHANOL TANKS)	45,000 litres	0.18×10^{-7}	Gasoline	20	80
Steel tank	9,500 litres	0.18×10^{-2}	Gasoline	20	80
			M100	20	25
			M85	20	29
Escape from tanker	30 litres/second	0.12×10^{-2}	Gasoline	10	40
			M100	10	13
			M85	10	15

The main sources of spills reported at methanol terminals are failures in transfer lines and overfilling of tankers. In case of ignition of these sources, the 1% fatality area can extend to 75 metres from the source. Overfilling of stationary bulk tanks is also a source of incidents. Typically, an escape of 13,000 cubic metres has been encountered which creates a potential for fire damage and injury up to 100 metres from the source. The chemical industry has minimized the hazard from such spills by special design of storage tanks (fire arrestors, inert blanketing of fuel, vapour collection).

The higher volumes stored, the increased pumping rates (or pumping times) required with methanol will increase the risk of spills compared to gasoline and in the introductory phase it will be important to segregate equipment, because methanol is aggressive to many metals and elastomers now used in storage equipment; filling lines and pump gaskets are particularly vulnerable items. These will be offset, however, by the 6 to 9-fold reduction in the area exposed to radiation damage from M85 or M100, compromised somewhat by the low flame visibility of M100 and the added risk this grade of fuel methanol poses to fire-fighters.

The conclusion is drawn that methanol storage facilities will be no less safe than those now handling gasoline and most probably significantly safer.

The recommendations are:

- conduct a comprehensive risk assessment study to guide M100 and M85 tank separation, tank volume and other site-related regulations. This is especially needed where M100 and M85 storage is added to an existing petroleum storage site and also where the blending of gasoline and methanol is undertaken
- evaluate fuel additives for luminosity

- develop automatic systems for monitoring methanol leaks and fires
- adapt chemical industry training and safety practices for use in the fuel industry and exposed fire-fighters.

Garaging of Methanol Vehicles

Canadian fire data (Exhibit 11) show that 50% of the 260 or so gasoline fires reported annually in Canada at stationary sites occur in residential garages and only about 8% in public parking facilities. Only 11% of gasoline fires occur at vehicle repair shops, despite the many sources of ignition that exist in repair facilities such as welding. Vehicle fires in garages and repair shops represented only 1.5% of all vehicle fires reported and explosions only rarely accompany fires.

Gasoline leaks from vehicle tanks due to failure or overfilling and thermal expansion rarely cause fires because ventilation is sufficient to disperse the vapours formed before the minimum fuel in air concentration necessary for combustion is reached. With large spills the concentration of gasoline in air may rapidly pass through the narrow flammable range before a an ignition source is contacted. Fires and explosions due to gasoline are most frequently caused by open storage of gasoline or its use as a solvent where gasoline vapours accumulate in drains or unventilated pits before locating an ignition source.

Exhibit 11
Gasoline Vehicle Fires at Stationary Sites

	% Total
Service stations, public	12.4
Service stations, private	6.7
Garage, residential	50.6
Parking, public	7.9
Bus, truck, fleet garage	11.2
Motor vehicle repair	11.2

Fires and explosions have been reported at chemical plants using methanol, but the risk of fires and explosions from M100 in unventilated garages is not known and tests of M100 and M85 in the environment are required. It appears from review of the properties of M100 and limited fire data that it is unlikely to be more hazardous from a fire risk viewpoint than gasoline in confined spaces (see Exhibit 12) but that the health risk from employee contact with the liquid may be somewhat higher. The health hazard from methanol vapours released in hot soak of the engine and in the exhaust will not be as significant a factor as the effect of carbon monoxide from the engine exhaust in poorly ventilated areas.

It is recommended that:

- data be generated on the fire and explosion hazard of M100 and M85 in confined areas
- an examination be conducted of the requirement for flame arrestors in vehicle fuel tanks, odorant in M100 and a revised ventilation regulation for M100 vehicles in repair shops and public garages.

Exhibit 12

Factors Affecting Safety of Methanol and Gasoline Confined Areas

FACTOR	EFFECT	RANK M100	RANK M85
Low ignition energy of M100	Majority of sources exceed energy for either fuel	±	±
Wide flammability concentration of M100 in air	Lower level of concentration will be more important than upper range and gasoline will ignite first in most circumstances	± to -	± to -
Low odour of M100	Spill may be undetected	-	±
Low energy content and radiant heat	Temperature above methanol pool lower than gasoline: less structural damage	+	+
Low toxicity and smoke in methanol fire	Reduced fatality rate from asphyxiation	+	±
Low flame visibility	Other components in this environment will normally produce adequate smoke	- to ±	±
Toxicity of methanol vapour	Carbon monoxide poisoning from engine in confined areas more toxic than gasoline or methanol	±	±
Volume of fuel in M100 vehicle increased	Offset by lower energy of combustion of methanol	±	±

Key: + is less hazardous than gasoline, - more hazardous, ± equally hazardous

7. SAFETY IN FUEL TRANSPORTATION

Perspective on Transportation of Methanol

Crude oil and petroleum products dominate transportation world-wide. In 1987 some 41% of the crude oil used was imported: 922.5 million tonnes of crude oil and 286.3 million tonnes of petroleum products were imported and exported, while even larger volumes of crude oil and petroleum products were transported within national borders.

A point of difference between methanol and gasoline or diesel fuel is that economics and logistics require that methanol be transported from plants located close to sources of natural gas to distribution terminals by ship, barge, rail or road tanker. With petroleum it is crude oil which is transported over long distances by ship, pipeline or barge to refineries located close to markets. The volatile and more flammable gasoline is hauled relatively short distances from refineries to terminals and even direct to service stations - most frequently by road tanker.

Road and Rail Movements

The U.S. data on spills of methanol transported by rail and road show only 65 spills per year on average, only 7% of which involved spills over 500 gallons (about 2 tonnes) or more. No casualties and only 14 fires or explosions were recorded in the period 1984-7. The data reflect the frequent local consumption of methanol near the production point (involving pipeline transfers).

In Canada methanol transportation is export-oriented and the spills recorded in road and rail transportation average only 3 per year, but they were substantial - comparable in size to spills encountered with gasoline tank trucks (8-9 tonnes/spill). Rail tanker incidents accounted for one third of the methanol spills in the transportation

sector and the size of shipments for export by rail is illustrated by the average spill size of 150 tonnes in this transport mode. There were no casualties in the transportation of methanol in Canada in the period 1982-6 examined.

As the volume of M100 and M85 increases, the movement of methanol will resemble that of gasoline with product moved from bulk terminals some 40-80 kilometres by segmented multi-product 33,000 litre capacity road tankers, and the rail movements in Canada will be replaced by pipeline movement of methanol through pipelines now dedicated to petroleum products, crude oil and LPG.

The major sources of road tanker incidents are expected to arise from vehicles overturning in poor weather and road conditions, tanker accidents which lead to large volume spills, and losses through defective valves and fittings which, though high in number (60% of incidents), normally lead to small volume spills.

The factors which may increase the safety hazard of methanol compared to gasoline in road and rail tanker movements include:

- higher freqency of fuel deliveries compared to gasoline (or crude oil)
- potential for explosion in partly filled tankers
- fire-fighters' unfamiliarity with the unique properties of M100, including low luminosity of the flame
- start-up problems in the period when petroleum and methanol fuels are both transported.

A higher frequency of problems due to corrosion and attack on elastomeric seals and hose may be encountered until methanol-compatible materials are substituted. These problems will be offset by the higher resistance to tank puncture when steel tanker constructions for methanol replace aluminum gasoline tanks, and reduced vulnerability of the

public, employees and buildings to heat, injury and damage which follow from the low radiant heat in methanol fires and the low toxicity of the combusted fuel.

On balance, the safety of road and rail transportation will be improved by the switch to methanol.

It is recommended that:

- the relative safety of M85 and M100 be investigated in the road and rail tanker environment
- detailed specifications be prepared for methanol tanker performance to guide designs of new and retrofitted single and multi-compartmented road tankers
- increased monitoring and control will be needed to prevent derailments, such as by the automatic detection of hot journal bearings
- the comparative risk of unit train and mixed cargo train movements needs investigation before major expansion of this mode is undertaken.

Waterborne Movements

The movement of methanol by ocean tanker is currently restricted by demand to 2000-6000 tonne and smaller cargoes shipped in dedicated stainless steel tankers, or convered small capacity oil tankers, petroleum product and LPG carriers. The switch to methanol will greatly increase the volume of international water movements by ocean tanker and eventually the size of methanol cargoes. In the U.S. barge movement of petroleum to the mid-West market from the Gulf coast may be switched to methanol movements. Barges and small ships as carriers for methanol are frequent in Europe and seven major incidents involving methanol were reported in western Europe in the period 1969-86 involving an explosion on a tanker in the Rhine and a number of fog-related collisions.

The problems to be encountered as methanol fuel use expands are similar to those involved in road and rail tanker movements (increased tonnage and frequency of shipments, use of vessels not yet reworked for methanol compatibility), but with the following also being important:

- methanol may not present a fire problem that is not already encountered in the movement of certain crude oils that are spiked with the very volatile butane (Alaska Slope and many heavier grades of Middle East crude)
- methanol cargoes can be pumped overboard in case of fire with little risk of continued burning or damage to the environment
- the intensity (heat radiation) from methanol fires will assist in the containment of on-board fires when they occur
- most important: the high electrical conductivity of methanol compared to gasoline and particularly to crude oil and fuel oil prevents the accumulation of static charges during fuel loading and unloading which is a frequent source of ignition with hydrocarbon fuels.

In view of the volumes of methanol which may be transported by water, it is recommended that a risk assessment study be conducted on the movement of methanol by barge on inland waterways, including an assessment of the large capacity loading and unloading systems, storage terminals and traffic control systems that will be necessary. The requirements of the design, construction, inspection and operation of methanol carriers should be precisely defined to guide new vessel construction and refitting for methanol.

Pipelines

Pipelining of methanol has been demonstrated in an LPG line (Cochin system) and in a crude oil pipeline where the methanol was preceded and followed by a gasoline buffer. The economy of scale and low operating costs will dictate long-range intracontinental pipeline

movements of methanol fuel.

Pipeline spills are infrequent but may be large: spills of gasoline from pipelines in Canada ranged up to 2300 cubic metres in 1982-7 and slow leaks can lead to large accumulation over time, such as a recent 1750 cubic metre leak detected in the Los Angeles area.

The problems foreseen with methanol pipelining are:

- small leaks of methanol may not be observable and accumulation may occur before detection
- movements in existing pipelines will require special clean-up procedures, rust inhibitors and perhaps pipeline rework, since methanol will dislodge rust and other debris and attack pipeline dope and rubber seals
- allowance must be made for water contamination in multi-product lines and for the recovery (treatment) of aqueous methanol fractions.

The high water solubility of methanol and its rapid biodegradation in soil will minimize the environmental damage and fire risk. The damage area surrounding an ignited methanol leak will be smaller than for petroleum pipelines.

The pipelining of methanol is to be encouraged as a safe transport mode in view of the low risk attendant upon the transport of even more toxic and flammable materials such as ammonia and LPG. Dedicated methanol pipelines will maximize safety.

It is recommended that the safety of pipelining methanol be confirmed by a risk assessment study and component test and that development be initiated of an automatic pipeline leak detection system.

8. CONCLUSIONS

It is apparent that the transportation and storage of methanol fuel presents a number of technological problems which can be solved. The key issue is the development of formulations which will burn with a visible flame, be detected by sight, odour and taste and which will not unduly compromise the environmental and safety attributes of M100.

Other important issues to be investigated include the toxicity of M85, leak detection and the severity and prevention of methanol fires in garages.

TP 9519

ASSESSMENT OF THE SAFETY OF TRANSPORTATION DISTRIBUTION AND STORAGE OF METHANOL FUELS

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16. Abstract

The study investigates risk and experience of incidents and problems expected when methanol is transported in bulk using conventional long-range transportation systems. It also addresses issues where methanol blends replace gasoline or diesel fuel at refuelling and vehicle repair lous. It provides an assessment of the safety of movements of methanol by pipeline, barge or lake tanker, by rail and long distance road tanker.

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16. Résumé

L'étude évalue le risque et fait le relevé d'incidents et de problèmes éventuels lorsque le méthanol est transporté en vrac par des systèmes de transport conventionels sur de longues distances. Elle étude également les cas où des mélanges de méthanol remplacent la gazoline ou le diesel pour fins de ravitaillement ou de réparation de véhicule. Elle présente une évaluation de la sécurité reliée au méthanol transporté par pipeline, péniche ou réservoir, par chemin de fer et camion citerne devant parcourir de longues distances.

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EXECUTIVE SUMMARY

An investigation has been made of the comparative safety of high methanol-content and conventional transportation fuels. This study was limited to safety in the storage, transportation and distribution of fuels containing in excess of 85 volume percent methanol, since studies by others have addressed safety in methanol-fuelled vehicles and the distribution of low methanol-content fuels.

It is concluded that methanol fuels will not increase the level of casualties and fire damage in storage and distribution systems beyond that now experienced with gasoline and may well reduce the casualty and damage level, particularly at service stations. The substitution of methanol fuels for diesel fuel is expected to degrade the level of fire safety in diesel domains, but to no greater degree than would be experienced if gasoline were substituted for diesel.

The outstanding advantage of methanol is that fires involving that fuel burn with a low radiant heat emission, therefore the area in which casualties and property damage occur will be substantially smaller than in gasoline and diesel fires (this is a key reason for the selection of methanol as a fuel in racing cars). This advantage will, however, be offset by a somewhat greater frequency of spills and perhaps also of fire incidents because of the higher volume of methanol required in vehicles compared to gasoline and diesel fuel.

Methanol distribution is not expected to increase the risk of toxic effect to industry employees when the comparison with gasoline includes the effect of the benzene component of most gasolines.

Development of means to prevent injury and fatalities through inadvertent and deliberate ingestion of methanol is an urgent requirement.

Introduction of methanol fuels will require some modifications to be made to current regulations on fuel safety, but an excellent basis already exists for the control and monitoring of spills of methanol in transportation, storage and distribution and for provision of information and human resources to assist local authorities in emergencies.

It is recommended that the regulations relating to the safety of transport fuels be revised to include requirements that are specific to methanol.

Further information should be obtained on the health consequences of substituting methanol fuels for conventional hydrocarbons. These considerations will include the anticipated public benefits which will arise from the reduction in ozone and particulates in the environment through use of methanol as a vehicle fuel and the effect of increased industry employee exposure to methanol.

More information is needed on the relative safety of methanol and gasoline in confined spaces, such as repair garages.

The safety of methanol can be improved by changes in the fuel and in means to detect spills.

It is recommended that a technical program be undertaken to facilitate these improvements.

Provided that the measures described above are undertaken promptly, there is no reason why the development of the methanol fuel market should be delayed by concerns over the relative safety of methanol compared to gasoline.

1. BACKGROUND

The Government of Canada is currently supporting a number of investigations and vehicle demonstrations of the use of methanol as a transport fuel. The fuel types investigated range from the use of 100% methanol as a replacement for diesel fuel in compression-ignition and spark-ignition bus and truck engines, to the use of methanol as an additive to gasoline - with and without the addition of cosolvents such as ethanol or butyl alcohol.

Alberta and Ontario exempt the methanol portion of motor vehicle fuels from provincial road fuel taxes. Consideration of similar tax forgiveness at the federal government level has been recommended.

In the U.S., methanol has been identified by the Department of Energy and the Environmental Protection Agency as the most plausible of the alternative fuels for use in the U.S. The Alternative Motor Fuel Act of 1988 established demonstrations and studies of alternative fuels with particular reference to methanol, compressed natural gas and electric vehicles.

There is already substantial use of methanol in gasoline blends in the U.S. and increasing support of large-scale demonstrations of methanol as a fuel for automobiles (Ford automobiles on test in California) and for city buses (demonstrations in Los Angeles, San Francisco, Seattle, Jacksonville and many more planned). These activities are proceeding, despite the current partial dependence on imports of Canadian and other foreign-sourced methanol, and a low level of experience on the health and safety implications of expanded methanol use.

Since Canada is a large market for U.S. automobiles, gasoline and diesel engines (Canada has no domestic production of diesel engines for highway use) and is a world-scale producer and exporter of methanol, it

is important that the health and safety implications of methanol use be investigated before methanol engines are introduced here on a commercial scale.

Methanol production in Canada in 1987 totalled 11.4% of the world production of 18.5 million tonnes, but Canada's consumption was only 1.4% of world consumption (see Exhibit 1.1). The three Canadian producers will be major suppliers of methanol to the U.S. fuel market and information on methanol fuel safety will be important to the development of that export potential and to the adoption of methanol as a vehicle fuel in Canada.

Canada has already developed a significant market for propane and natural gas in the transportation sector and a body of experience, information and regulations which control the safety of these fuels in storage, during distribution and in conversion, repair, garaging and refuelling of propane and compressed natural gas vehicles. A corresponding body of information has still to be developed on methanol fuel safety, since the present experience with methanol is essentially limited to its distribution and use within the chemical industry and trials as vehicle fuel.

The perceived wisdom that methanol safety is not significantly different from that of gasoline may be correct in vehicles, but may not be so in the transportation, storage and distribution sectors. The climate and transportation infrastructure in Canada is different from that in Europe and the U.S. and special problems related to the Canadian environment need identification. This report therefore addresses the Canadian situation while drawing substantially on excellent previous reports on methanol safety by P. Machiele of the U.S. Environmental Protection Agency, and on methanol technology by the International Energy Agency and the U.S. Department of Energy (Alcohol Fuels Program).

Exhibit 1.1

Perspective on Canadian Methanol Production and Demand

	Production	Demand
	Tonnes/Annum 1987	
International		
Canada	2,100,000	250,000*
USA	3,160,000	4,572,000
World	18,500,000	18,000,000
Canada		
Alberta Gas Chemicals (Alta.)	850,000	
Celanese (Alta.)	850,000	
Ocelot (B.C.)	400,000	
	2,100,000	

* Balance is export

Natural gas required for current methanol production is equivalent to 4% of natural gas sales.

Canadian methanol production in energy terms is equivalent to:
1.6% of oil refinery output of petroleum products
4.1% of gasoline sales and 2.8% of gasoline and diesel sales
11% of LPG (Liquefied Petroleum Gas) production
16% of LPG use in Canada
the fuel consumption of about 650,000 automobiles.

Source: Canadian Oxygenated Fuels Association

1.1 Scope and Objectives

The assessment is limited to the safety of methanol fuels and a comparison with gasoline and diesel in bulk transportation (ship/barge, rail and pipeline modes), distribution (by tank truck and at service stations), and storage (at bulk terminals and service stations). Vehicle repair is also included, but vehicle operation is not, since this has been reported on previously.

Methanol fuels are defined as fuels containing between 100% methanol (M100) and 85 volume % methanol 15% gasoline (M85).

The scope of the safety assessment includes the frequency and magnitude of methanol spills ("loss of containment"), the frequency and effects of fires and explosions and notes on the toxicity of the fuel.

The objective is to provide information to facilitate the development of the legislation, equipment, training and emergency response capabilities.

2. METHANOL AS A TRANSPORT FUEL

2.1 Reasons for Adoption of Methanol Fuel

A variety of energy sources and engines has been considered for highway transportation but engine production technology, resource availability and fuel cost considerations led to the adoption of gasoline used in spark-ignition ("Otto cycle) engines and diesel fuel in compression ignition ("diesel cycle") engines as the dominant combinations. The oil price increases and supply concerns of 1973 and 1979 stimulated commercial use of CNG and propane, as they could be used in slightly modified current technology engines.

Methanol is currently used as a minor component of gasoline blends (3-5% by volume frequently with the concurrent use of a similar volume of a cosolvent such as butyl or methyl alcohol) and as a building block for the manufacture of MTBE (methyl t.butyl ether) which is increasingly being used as an octane enhancer in the production of unleaded gasolines. In 1988 production of MTBE in the U.S. is at an annual rate of 1.5 million tonnes, but MTBE is not yet manufactured in Canada.

The market for high methanol-content fuels, M100 to M85, has been limited by the high cost of methanol relative to gasoline and diesel fuel, by incompatibility of methanol fuel with the current distribution system (particularly with a number of metals, alloys and plastics used in the gasoline system), and by the requirement to develop new technology for the use of methanol fuels in diesel engines. The slow development of the methanol fuel market may not prevent that fuel from becoming the dominant alternative to diesel and gasoline, since a number of factors favour its adoption.

The key factor affecting the future adoption of methanol, CNG or propane is the anticipated benefit to public health and reduced crop damage which will accompany the reduction in the level of ozone, carbon

monoxide and particulates in the environment. Production of ozone is related in a complex way to the irradiation of unburned hydrocarbon and nitrogen oxides (NOx) in the air. Over 60 communities in the U.S. do not comply with the current ozone requirement of the National Ambient Air Quality Standard (0.12 parts per million in air hourly average once per year). Similar levels of non-compliance exist with carbon monoxide.

The urban air quality in a number of Canadian cities is also inadequate and can be traced in large part to vehicle emissions: 20% of the NOx released in Canada, 24% of the hydrocarbon emissions and 45% of the carbon monoxide are attributed to automobile emissions.

Exhibit 2.1 illustrates the level of reduction of vehicle emissions which may be achieved using M100 or M85. Other factors affecting the future adoption of methanol, CNG and propane as alternatives to gasoline or diesel fuel are summarized in Exhibit 2.2. As with methanol, CNG and propane can be used in vehicles dedicated entirely to the alternative fuels or adapted to operate on either the alternative or the conventional fuel. The advantage of the recently developed methanol flexible-fuel vehicle is that it can operate on a mixture of methanol and gasoline in any proportion, whereas the gaseous fuels are used in dual fuel systems where the engine operates on either the alternative or the conventional petroleum fuel. Use of the conventional fuel in flexible or dual-fuel vehicles reduces the environmental benefit of using the alternative fuel, prevents optimization of the engine, and retains many of the safety advantages and disadvantages of each of the fuels.

Exhibit 2.1

Standards and Typical Vehicle Emissions

	CO	NOx	Exhaust Hydrocarbon
AUTOMOBILES AND VEHICLES WITH EMISSION CONTROL SYSTEM		(grams/mile)	
Standard 1988+ maximum	3.4	1.0	2.0
M100 in test vehicle	2.2	0.6	0.15
M100 as % gasoline in same vehicle	45	90	40
M85 as % gasoline in other test vehicles	185	84	65

	CO	NOx	Exhaust Hydrocarbon	Particulates
HEAVY DUTY VEHICLE BUS WITHOUT EMISSION CONTROL SYSTEM		(grams/brake horse power hour)		
1991 bus standard (1994 truck), max.	15.5	5.0	1.3	0.1
M100 engine test	2.55	3.0	0.6	0.02*
M100 as % diesel in same engine type	45	30	50	1

* Particulates in diesel engines without particulate traps frequently exceed 1991 EPA standard by factor of 2-5

Exhibit 2.2

Factors Affecting Adoption of Alternative Fuels

FACTORS AFFECTING ADOPTION		METHANOL RANK	METHANOL DESCRIPTION	PROPANE RANK	PROPANE DESCRIPTION	CNG RANK	CNG DESCRIPTION
VEHICLE RELATED	Engine availability						
	- autos	+	Flexible fuel vehicle can use either gasoline or methanol blends	+	Minor modification of gasoline engine	+	Minor modification of gasoline engine
	- trucks, buses	+/-	Low availability of heavy duty engines but several potential suppliers	+/-	Conversion of diesel is complex, engine and kits not yet widely available	+/-	Conversion of diesel is complex and engine kits not yet available
	Vehicle conversion capability	+	Manufacturers not interested and no conversion industry is likely to develop	+	Many shops capable of conversions but limited range available from manufacturers	+	Conversions available
	Vehicle conversion cost	-	$300 premium for autos, $1700 for diesel truck, bus	-	$700 conversion cost for autos, $1400 for trucks	-	$2600-3000 auto conversion cost, offset by $500 federal grant
FUEL RELATED	Ease of refuelling	+	Same as gasoline and diesel because liquid	+	Similar to gasoline but pressure system	-	Slower than gasoline, more complex (high pressure system)
	Resource availability	+	Based on surplus gas	+	Surplus propane available	+	Large surplus available
	Local fuel availability	+/-	Not yet distributed but no problem	+	Available at over 4000 locations	+/-	130-140 stations in urban centres
	Fuel cost (annual) for vehicle	-	Not competitive: need subsidy	+	Cost savings up to 40% available	+	Cost savings up to 50% available
PERFORMANCE RELATED	Range	-	Needs 1.8 times fuel tank volume of gasoline, 2.3 times diesel	+	Typically 80+% of gasoline range (dual-fuel systems overcome this)	-	Typically less than 50% of gasoline (dual-fuel systems overcome this)
	Vehicle performance (acceleration)	+	Superior to gasoline and diesel	+	Equivalent to gasoline	-	Somewhat less than gasoline
	Vehicle carrying capacity	+	Essentially unchanged from gasoline and diesel	+/-	Added volume of propane tank occasionally a disadvantage	-	Large increase in volume and weight of storage tanks limits acceptance
	Exhaust emissions	+	Cleaner burning than gasoline and diesel	+	Cleaner burning than gasoline and diesel	+	Cleaner burning than gasoline and diesel
SAFETY RELATED	Fire safety	+	As safe as gasoline, less than diesel	-	Somewhat less safe than gasoline	+	As safe as gasoline and diesel
	Toxicity	-	Similar to gasoline, worse for ingestion	+	Essentially non-toxic	+	Essentially non-toxic

KEY: + Positive factor for conversion decisions
- Negative factor for conversion decisions
Methanol is M100 or M85

3. FACTORS AFFECTING THE SAFETY OF METHANOL

3.1 Distribution Infrastructure

The conventional fuel system is based on the long-distance transportation of crude oil by ocean tanker and/or pipeline to refineries located close to markets from which gasoline, diesel fuel and other refined products are distributed - most frequently by road tanker direct to service stations or short pipeline/road tanker combinations through bulk terminals, and less often by barge or rail tanker.

Movements of the more volatile and hazardous gasoline and diesel fuel are therefore limited. Exhibit 3.1 illustrates the point from spill data on petroleum products for the 10-year period 1974-83. During that time the number of spills of gasoline was 13% of that of crude oil spills, whereas the volume of gasoline produced in the period was 31% that of crude oil. The average size of crude oil spills was twice that of gasoline (17.2 tonnes and 6.6 tonnes/spill average).

In contrast with the petroleum system, current and proposed future manufacture of methanol is favoured economically when close to the gas resource. Vehicle methanol is transported over long distances by combinations of ocean tanker, barge, rail and road tanker, although the feasibility of pipeline movements in crude oil and gas liquids has been demonstrated in Canada.

The low energy content of methanol relative to petroleum products (see Exhibit 3.2) requires that higher volumes of methanol must be transported. Since petroleum product movements and storage systems are most frequently designed to meet vessel, tanker and tank capacity regulations, the frequency of vessel and tanker movements and the number of storage tanks must be increased for methanol use.

Exhibit 3.1

Relative Frequency and Volume

of Crude Oil, Gasoline and #2 Fuel Oil Spills

(Canada 10 Year Period 1974-83)

MATERIAL SPILLED*	% # SPILLS	% TONNES SPILLED
Crude Oil	41.2	52.7
Fuel Oil #2**	21.6	16.9
Fuel Oil #4,5	7.2	8.8
Gasoline	13.4	6.6
Other Oils	16.6	15.0

Average "oil" spills #/year 1,626

Average volume of spills/year 21,850 tonnes

Average volume per spill 13.45 tonnes

* Excludes gases and condensates

** Includes diesel fuel

Source: Calculated from data in report Environment Canada report Summary of Spill Events in Canada, 1974-83, Rept. EPS/5/SP/1

Exhibit 3.2

Volumetric Factors Affecting Transportation of Methanol

	Light Crude Oil	Gasoline	Diesel	Methanol M100	Methanol M85
Energy content relative to gasoline, %	111	100	112	49	57
Volume of fuel/unit energy relative to gasoline, %	90	100	90	204	176
Volume required in vehicle relative to gasoline, %	N/A	100	130	180	168
Volume required in vehicle relative to diesel, %	N/A	128	100	230	215

The high efficiency of methanol compared to gasoline in spark ignition engines reduces the fuel volume required below that calculated on an energy density basis, but overall the replacement of gasoline and diesel fuel by methanol increases the volume of fuel and consequently the frequency of spills. On this basis spills of methanol would be increased by a factor between 1.8 (gasoline replacement) and 2.3 (diesel replacement), or a factor of 2 if gasoline and diesel fuel are replaced in proportion to the volumes used in Canada in 1987.

The frequency of spills is, however, also related to the surface area of storage tanks, pipes and hose exposed during fuel storage, transfer and transportation. Surface area considerations result in a somewhat lower scale-up factor for methanol than that given above. The combination of energy content, vehicle fuel efficiency and surface area effects probably lead to a 1.5-fold increase in the likelihood of spills when methanol replaces gasoline and about 1.9 when diesel is displaced, or an average of about 1.7 when methanol replaces both fuels.

3.2 Methanol Properties Related to Safety and Handling

The key properties critical to the safe storage and transfer of methanol are discussed below in the context of their contribution to spills, the ignition of spills, the propagation of fires and explosions, and toxic effect. The pathways between the loss of containment (spill) and effects on individuals and property are illustrated in Exhibit 3.3.

3.3 Factors Affecting the Frequency and Size of Spills

As noted above, the effect of the increase in the volume of methanol required in vehicles increases the potential for spills compared to gasoline and diesel fuel throughout the system.

Methanol is corrosive to aluminum, magnesium, copper, zinc, lead and to alloys such as brass used in fuel system fittings, and to terneplate used in the production of most gasoline and diesel vehicle fuel tanks. Gasoline and diesel have no effect upon these metals. Anhydrous methanol is not corrosive to mild steel, but addition of only 0.5% water induces corrosion. Methanol is a strong solvent for many plastic materials, adhesives, pipe dopes and elastomers. Many of the plastics and elastomers commonly used in vehicles, tanks and in fuel hoses swell or crack after repeated exposure to methanol. The methanol distribution system must therefore be designed with selected methanol-tolerant materials and storage facilities to avoid water pick-up. Thus, aboveground storage tanks of mild steel are acceptable if water pick-up is avoided. Special methanol-resistant resins must be used in fibreglass tank construction. Methanol-resistant plastics such as polyethylene, polypropylene, acetates and fluorinated elastomers are preferred at other points in the distribution system. Exhibit 3.4 summarizes data on methanol material compatibility.

Exhibit 3.3

Schematic of Methanol Exposures

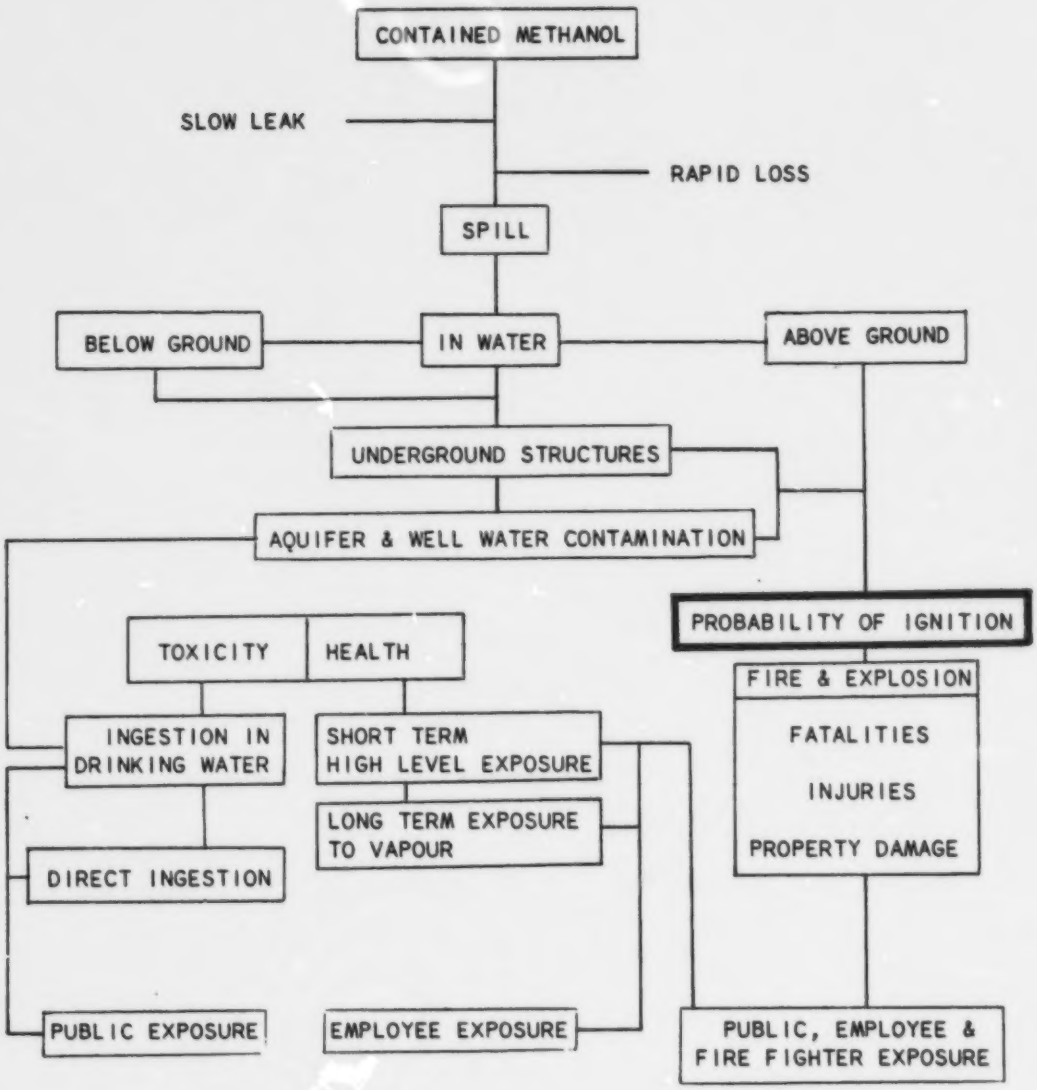


Exhibit 3.4

Methanol (M100) and Material Compatibility Problems

	Frequently Reported	Occasional	No Problems
PLASTICS, RESINS	Fibreglass/polyester	Polyamide (nylons), wet methanol	Polyacetyl resins
	Natural rubber	Nitrile rubber	Polypropylene
	Polyurethanes	Polyvinyl chloride (PVC)	Fluorosilicone rubber
	Epoxy resins		
	Polymethylmethacrylate		
	Viton		
	Cork		
	Leather		
	Carbon composite		
METALS	Magnesium	Aluminum, wet methanol	Cadmium
	Copper	Steel	Antimony
	Lead	Brass, wet methanol	Tin
	Cast iron	Terne	Bronze
		Zinc	

The current chemical methanol distribution system has been designed to avoid these material incompatibility problems, but in the period of transition to the use of methanol fuel, it is certain that the existing gasoline distribution system and maintenance practices will be used and a higher frequency of spills due to corrosion and/or material failures will occur in the methanol, gasoline and diesel fuel system. These will not be present in dedicated fuel methanol systems.

Where methanol is stored underground, the precautions taken against corrosion will need to be as stringent as with gasoline and diesel where a significant voluntary tank replacement program is being undertaken by the petroleum industry in view of the frequency of leaks that have occurred from corroded tanks and piping.

In gasoline distribution it is recognized that 0.4-0.6% of the liquid volume is lost as vapour to the atmosphere as gasoline is moved from the refinery to the consumer through the intermediate stages of storage, transportation and fuel dispensing. The volume lost through vents, tank manholes and at vehicle tank inlets is dependent on the vapour pressure of gasoline, fuel temperature and the agitation and speed at which the product is pumped. The lower vapour pressure of M100 and diesel will reduce vapour losses compared to gasoline by at least a factor of 2, but losses with M85 will be comparable to gasoline. The reduction of emissions from methanol fuel transfer and vehicle fuelling is an important environmental benefit in regions such as Los Angeles where ozone levels must be reduced.

3.4 Factors Affecting the Frequency and Severity of Methanol, Gasoline and Diesel Fires

The key properties of fuels which affect spills, ignition, fire and health hazards are summarized in Exhibit 3.5. A summary of the effects of these properties on safety is given in Exhibit 3.6. Technical terms used in the report are summarized in the Glossary.

Exhibit 3.5

Fire-Related Properties of Methanol and Petroleum Fuels

	M100	M85	Gasoline	Diesel
Liquid density at 15°C (g/litre)	800	745	735	820-860
Vapour density relative to air	1.11	2*	3.4	5-6
Boiling point °C	64.5	30-225	30-200	100-380
Flash Point °C	10	-43	-43	52
Auto-ignition temperature °C	385-480	222-480	222-425	220-315
Minimum energy for ignition in air MJ	0.14	0.14	0.24	0.24
Flammability limits (% volume in air)	6.7-36.5	2-34	1.4-7.6	0.7-5.0
Vapour pressure at 38°C kg/cm2	0.32	0.32	0.6-0.8	low
Heat of vapourization MJ/kg	1.1	0.98	0.3-0.34	0.25
Heat of combustion MJ/kg	19.6	23.2	43.5	42-43
Heat capacity of liquid MJ/kg,°C	2.408	2.376	2.194	-
Electrical conductivity, units	$3x10^{7}$	$2x10^{7}$*	3-10	50-100
Flame spread rate, metres/sec	2-4	3-5 *	4-6	0.02-0.08
Peak flame temperature, liquid fuel, °C	1965	N/A	2190	2150-2250

* Estimated

Exhibit 3.6

Summary of Influence of Properties on Fuel Safety

KEY PROPERTY	SAFETY RELATIVE TO M100		
	Gasoline	M85	Diesel
Vapour pressure (volatility)	-	-	+
Flash point	-	-	+
Auto-ignition temperature	-	-	-
Flammability limits in air	+	+/-	+
Heat of vapourization	-	-	-
Heat of combustion	-	+/-	-
Electrical conductivity	-	+/-	-
Flame luminosity	+	+	+
Peak flame temperature	-	+/-	-
Flame spread rate	-	-	+
Radiant heat from fire	-	+/-	-
Toxicity of vapour	+/-	+/-	+
Toxicity of ingested liquid	+	+/-	+
OVERALL ASSESSMENT			
Fire risks	-	+/-	+
Toxicity risks	+	+/-	+

* Lower heat of combustion of methanol somewhat offset by the increased volumes (systems throughput) which must be used compared to gasoline and diesel.

KEY: + fuel is considered safer than M100
- less safe
+/- about the same as M100

3.4.1 Flash Point and Boiling Point: Fuel Classification

The properties of fuels considered most significant in the development of safety standards are the flash point and boiling point.

The classification of fuels from a safety viewpoint can be illustrated by reference to the standards and classifications recommended by the U.S. National Fire Protection Association (NFPA) which have been adopted throughout N. America and incorporated in most state and provincial fuel safety regulations. The key distinction made is between fuel gases and liquids. From a fire protection viewpoint gases, such as natural gas and propane, are defined as materials with a vapour pressure higher than 40psi absolute at 100°F (37.8°C).

Liquid fuels have lower vapour pressures and can therefore be stored in vented tanks and transferred between storage tanks as liquids at atmospheric pressure. Liquid fuels are classified on the basis of flash point and boiling point.

The flash point provides an indication of the fire risk in storage under ambient conditions and in particular to the minimum temperature at which a fuel can be ignited in air by an initiating high energy source such as a flame or spark.

Diesel fuel has a flash point above 37.8°C (100°F) and is classified by NFPA as a COMBUSTIBLE LIQUID.

Gasoline has a flash point below 37.8°C and a vapour pressure not exceeding 40psi at 37.8°C. It is in the class of FLAMMABLE LIQUIDS. The NFPA further divides flammable liquids into those with a boiling point below or above 37.8°C. Gasoline is a Class 1A liquid with a boiling point below 37.8°C. M85 would normally contain a low boiling gasoline or hydrocarbon fraction to provide improved engine cold starting and perhaps improved flame luminosity; it is also Class 1A.

Methanol with a boiling point above 37.8°C is a Class 1B flammable liquid. The differences experienced in fire risk between combustible and flammable liquids and between Class 1A and 1B flammables are such that the classification is used as a measure of the volume of the fuel that may be stored inside.

3.4.2 Volatility, Heat of Vapourization and Energy Content

M100 is less volatile than gasoline or M85 but substantially more volatile than diesel fuel. Diesel fuel vapour losses on storage in vented tanks and at fuel transfer are therefore exceptionally low and the risk of vapour ignition is correspondingly low. Gasoline is at the other end of the spectrum. The volatile front end (butanes and other light hydrocarbons which contribute to the ease of cold weather starting) is a major factor in the risk of ignition of gasoline spills. M100 vapour availability to ignition sources is intermediate between gasoline and diesel fuel. M85 is designed to provide a volatile front end and therefore resembles gasoline.

The lower energy content and higher heat of vapourization contribute in a major way to the lower risk of fire damage and injury from an M100 fire compared to hydrocarbon fires. When M100 vapourizes, it cools the liquid pool and this slows the rate of vapourization. The low heat of combustion of M100 compared to gasoline or diesel fuel also means that much larger volumes of methanol must be burned to offset the heat of vapourization. It has been calculated that the ratio of fuel volumes needed to sustain vapourization is about 8.5:1 for methanol compared to gasoline and perhaps greater than this when a comparison is made with diesel fuel.

The combined effect of the low energy content and high heat of vapourization of methanol on the temperature surrounding a methanol fire is dramatic when compared to those for hydrocarbons.

Exhibit 3.7 illustrates the temperatures recorded in experiments where similar pools of methanol and JP-5 distillate were burned in air. JP-5 is a jet fuel very similar in properties to #1 diesel fuel. While the temperature immediately above the burning methanol pool was higher than that above the slower burning distillate, the temperature above the methanol flame fell rapidly with distance, while that measured above the hydrocarbon pool did not.

Exhibit 3.7

Methanol and Jet Fuel Fire Measurements

	Temperature °C above ambient	
Distance above burning pool surface	Methanol	JP-5
1cm	750	500
40cm	500	500
120cm	250	500

Source: Alger et al., "Some Aspects of Structures of Turbulent Pool Fires," Fire Technology, Vol.22, #2, 1986.

The low heat of combustion of methanol is a consequence of its oxygen content and correspondingly lower hydrogen and carbon content compared to hydrocarbon fuels. Methanol cracks in the vicinity of the flame to form carbon monoxide and hydrogen, which burn smoothly in air with a low luminosity and low radiant heat. In contrast, gasoline and diesel fuels crack to a variety of gases and also produce carbon (soot) which contributes to the high luminosity and radiant heat of hydrocarbon flames. The following description by Alger, Carlett, Gordon and Williams illustrates the difference in the structure of methanol and distillate fires: "In the JP-5 fire, the upwardly billowing, soot-filled and burning eddies bear no resemblance to the short, horizontally moving, transparent whirls with vertical axes seen dimpling the liquid surface of methanol."

Although gasoline normally burns with less cracking than diesel fuel, the same characteristics and temperature-distance effects occur with this fuel.

3.4.3 Flammability and Ignition Sources

Heavy fuels such as diesel have flash points well above ambient temperature. The vapour pressure over the fuel at ambient temperatures is too low in hydrocarbon ("too lean") to support ignition, even in the presence of a localized high-energy spark or flame. At high temperatures, such as those encountered after compression of a fuel-air mixture in the cylinder of a diesel engine, the fuel may combust spontaneously (termed "auto-ignition"). This may also occur in a fire or the hot fuel may vapourize to produce an air-fuel mixture rich enough to be ignited by a spark or open flame. If the air-fuel mixture becomes too rich, it will pass through the flammability range of air-fuel concentration and will not burn, even at high temperatures. The flammability range for diesel fuel is narrow, starts with a low concentration of fuel in air (only 0.7 volume %) and passes through the flammability range while the fuel-air mixture is still lean (5% fuel in air).

Gasoline has a lower flash point than diesel, but a similar auto-ignition temperature and a similarly narrow flammability range (1.4 to 7.6 volume %). As with diesel this means that gasoline spills in an enclosed space, for example, rapidly reach vapour compositions which do not burn but could be diluted by ventilation to the point where combustion could still be initiated by a spark or flame.

M100 behaves differently. The flash point is higher than that of gasoline, but still within the range of temperatures encountered in enclosed garages and outdoors in Canadian summers. The flash point of 10°C (50°F) may be a distinct advantage when spills outdoors occur in Canadian winter conditions, whereas gasoline will still be ignited by a

spark in winter temperatures.

The somewhat lower ignition energy required to ignite M100 than gasoline is not a substantial disadvantage since most ignition sources have energies substantially in excess of those required to ignite gasoline, methanol or diesel fuel when present at the appropriate concentration in air. Furthermore, since methanol is a good electrical conductor, static charges do not build up on surfaces exposed to the liquid or vapour. The high resistivity (low conductivity) of diesel encourages the development of static charge during fuel movement (transfer) and is a frequent source of fuel oil ignition. The static charge effect must also be guarded against with gasoline.

The last factor to be considered here is the peak flame temperature in methanol fires. Due to its ease of dissociation into its components of carbon monoxide and hydrogen, and the cooling effect of the high heat of vapourization of liquid methanol, the peak temperature reached in methanol fires is lower than that experienced in liquid hydrocarbon fires. This, coupled with the low radiation from methanol fires, substantially reduces the heat flux outside the burning liquid fuel area compared to gasoline or diesel fuel. (These characteristics were important in the selection of methanol as the fuel for racing cars.)

3.4.4 Fire Risk Assessment

The combination of properties which define the behaviour of M100, M85 and gasoline in fires was used in a formal risk assessment evaluation conducted for this investigation by the Industrial Safety Branch of the Netherlands Organization for Applied Scientific Research (TNO). The results for fires involving the same substantial volumes of burning M100, M85 and gasoline are summarized in Exhibits 3.8 and 3.9.

Exhibit 3.8

Damage Distances for M100, M85 and Gasoline

Radius of Pool (100% fatalities)	Heat Radiation (1% fatalities)		
	Gasoline	M100	M85
20	80	25	29
10	40	13	15
1	5	1.5	1.7

Note: Heat radiation at 1% fatality level is 7.5kw/m2

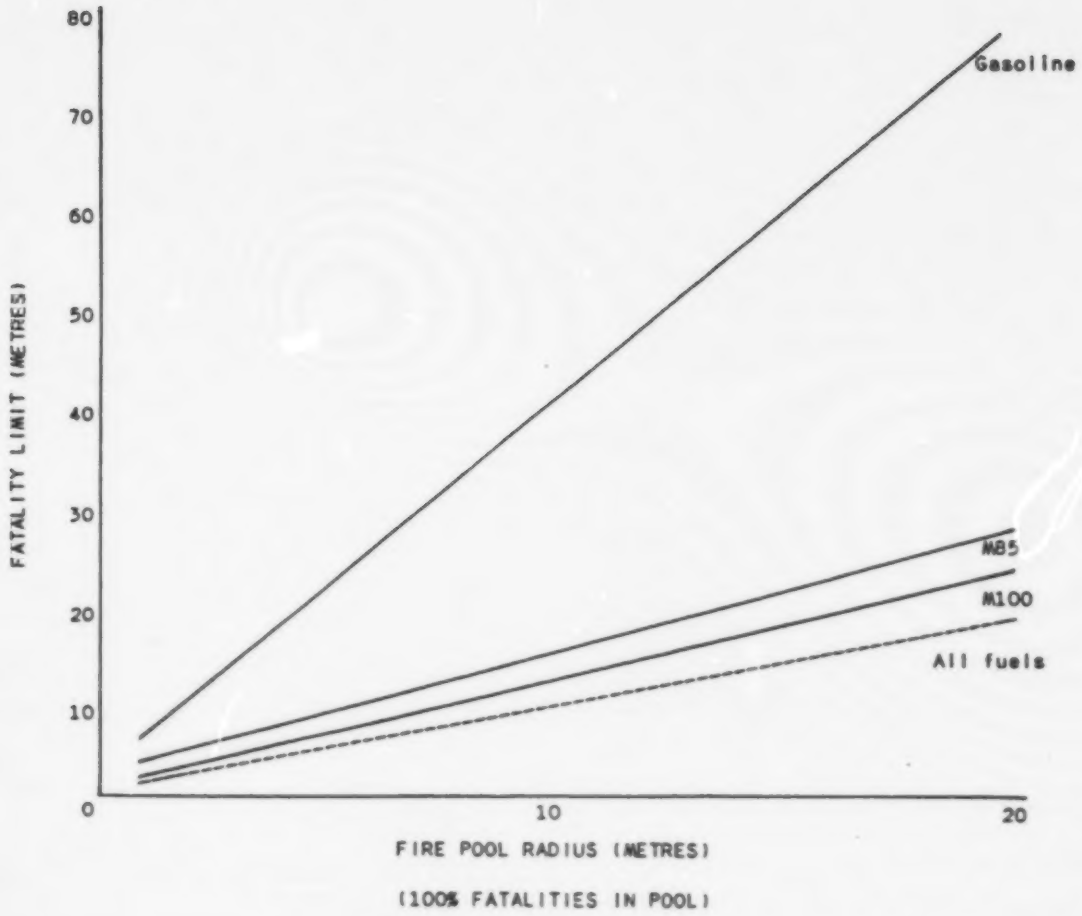
The fatality rates of persons within the burning liquid pool areas will be the same (100% for the 3 fuels). The distance from the centre of the pool fire to the area in which fatalities from radiant heat are expected to be 1% or more corresponds to a heat radiation level of 7.5 kilowatts/m2 or more. The distance is 3 times higher for a gasoline fire than for an M100 fire and about 2.7 times greater for gasoline than for M85. In other words, the area within which a 1% fatality rate is expected with gasoline is 28 times that for a similar volume M100 fire and about 23 times that for a fire involving the same volume of M85.

Even when allowance is made for the higher annual volume of M100 or M85 required compared to gasoline, it is clear that the area exposed to fire and casualty risk is substantially lower for methanol than for gasoline.

Although a diesel fire can cause fire damage and casualties no less than gasoline, diesel fire data is not emphasized in this assessment because of the low frequency and designation of diesel as a combustible, rather than a flammable fuel, in safety regulations.

Exhibit 3.9

Fatality and Damage Distances for Methanol and Gasoline Pool Fires



Key: ———— 1% fatality distance

– – – – – – 100% fatality

3.5 Key Factors Affecting Fire-Fighting

Exhibit 3.10 summarizes the hazards of different fuels to fire-fighters and emergency personnel.

3.5.1 Leak and Fire Detection

Methanol leaks and fires are much less readily detected than hydrocarbon fires and the danger exists that emergency personnel may underestimate the risk involved and even unknowingly enter the fire or fire hazard area.

Methanol is colourless, has a low odour, burns with a flame that may be invisible in daylight until it encounters oils, gasoline, furniture or vehicles. Its detectable threshold in air is about 50ppm compared to 10ppm for gasoline or diesel. Methanol fires do not radiate heat over long distances and since methanol is soluble in water, methanol spills do not provide a visible slick on the water surface - as do gasoline and diesel fuel - even though the solution may contain enough methanol to be combustible. A search is underway for appropriate additives to provide colour (dyes), odour (added odourants such as those used in propane and natural gas) and persistent luminous flames (addition of aromatic hydrocarbons).

Use of gasoline as an additive in the formulation of M85 or similar fuels provides a partial solution by contributing odour and a level of flame luminosity, but further work on methanol fuel formulation is required, since gasolines provide a level of luminosity which persists throughout the fuel burn only when they contain soot-generating aromatic materials such as benzene, toluene and xylenes. A high aromatic content in methanol fuel is undesirable in view of the carcinogenicity of benzene and the high photo-activity of xylenes which contribute to the ozone burden of urban environments.

Exhibit 3.10

Hazards to Fire-Fighters from Fuel Fires

	SAFETY RELATIVE TO M100		
	Gasoline	M85	Diesel
Fire detection	+	+	+
Fire containment/spread	-	+/-	+
Severity of fire	-	+/-	-
Explosion hazard	-	-	+
Heat effects on fire-fighters	-	+/-	-
Inhalation injury	-	+/-	-

OVERALL ASSESSMENT

The difficulty of detection of M100 fire is a serious drawback. In other respects M100 is less hazardous to fire-fighters than gasoline and M85 and about equivalent to diesel fuel.

KEY: + fuel is considered safer than M100
- less safe
+/- about the same as M100

3.5.2 Fire Spread and Severity

The principal tasks for fire-fighters at a fire site are to prevent expansion of the fire and then to extinguish it. While the size of the fire is determined by the volume of fuel involved, the properties of the fuel also determine the severity of the fire, the speed with which it spreads and the ease with which it may be contained and

extinguished. There are also significant differences in the relative hazards of fires in open spaces and those where fuel and fire are in enclosed spaces - buildings and fuel tanks.

Diesel fires burn in open air producing intense radiant heat and smoke which inhibit close approach of fire-fighters and equipment. The radiation will frequently initiate secondary fires in trash, buildings or in fuel stored elsewhere on site and in vehicles.

Gasoline is substantially more hazardous than diesel fuel, although the radiant heat and smoke output per litre of fuel combusted may be somewhat lower than that from a similar volume of diesel fuel. The rapid and often erratic growth of gasoline fires contributes to the high hazard. The speed of the gasoline flame on a pool of spilled fuel is much higher than that of diesel fuel (100-fold), gasoline rapidly vapourizes and since the vapour is 3-4 times as dense as air, it spreads along the ground and may accumulate and ignite in drains, ditches, underground garages and basements. Explosions may accompany the fire and both can occur, even at low fuel concentrations in air.

M100 is much less hazardous than gasoline to fire-fighters in open air fire situations. An M100 fire will burn with low emission of radiant heat and an essentially smokeless flame. Fire injury, property damage and the potential for ignition of secondary fires are all reduced, due to the low heat of combustion, and high heat of vapourization. The lower vapour pressure (volatility) and high auto-ignition temperature of M100 also reduce the hazard of methanol fires being initiated by other fires on site. Methanol vapours are only slightly more dense than air (1.1:1) and methanol vapours therefore mix more readily with air and accumulate in low lying areas to a much lesser degree than gasoline.

Water can be used effectively to extinguish methanol fires providing sufficient is used to reduce the methanol concentration below the flammability threshold of 21% methanol.

The addition of gasoline to form M85 severely compromises the safety of methanol fuels, since the problems due to gasoline vapour spread, ignition and smoke are introduced and use of water leads to separation but continued burning of the upper layer of gasoline, while the aqueous lower layer may also be combustible at high methanol concentrations.

M100 is on balance more hazardous than M85, gasoline and diesel fuel where the fuel is contained in an open storage tank or spilled in large volume inside garages or other enclosed spaces.

The change in rating is attributed principally to the low detectability of methanol and to the wide flammability range of methanol in air. Under conditions where ventilation is limited, the low vapour density of methanol (compared to hydrocarbons) and the high diffusion rate can lead to dispersion of M100 in air and the rapid attainment of the lower flammability range: further leakage and vapourization of methanol will continue to build fuel-air concentration within the wide flammability range. With gasoline and M85 fuel, vapourization also rapidly leads to the lower flammability concentration level but as the fuel concentration grows the fuel-air mixture soon moves beyond the flammability range and becomes too rich to burn. Diesel fuel has such a low vapour pressure that the air-fuel mixture concentration above the fuel is too lean to burn unless there is a substantial fire in the vicinity.

The major hazard to fire-fighters from methanol therefore arises from the poor detectability of methanol spills and fires and from the spread of fires to methanol stored in exposed aboveground vented storage tanks or spilled in enclosed spaces.

3.5.3 Injury

Replacement of diesel and gasoline by M100 will reduce the level of burn injuries and instances of fire stroke and heat exhaustion in fire-fighters. The clean-burning nature of M100 will also reduce the level of smoke inhalation experienced by fire and rescue teams. Use of M85 will lead to only a partial improvement in fire-fighter injury compared to gasoline and diesel fuel.

Large spills of methanol and methanol vapour from fires can lead to fire-fighter exposure, particularly in enclosed spaces. Short-term exposure at concentrations in air of 25,000ppm can be fatal. Various authorities recommend different but low levels of exposure to methanol. The maximum exposure over a 15-minute period set by the National Institute of Occupational Safety and Health in the U.S. (NIOSH) is 250ppm; this compares with 500ppm for gasoline. Diesel is too involatile to be a serious short-term health factor. Safety regulations require that fire-fighters wear self-contained breathing apparatus and protective clothing in fires involving methanol, gasoline or diesel fuel. The need for self-contained breathing apparatus is principally to ensure full functionality when the oxygen concentration in the vicinity of the fire is reduced to 19.5%, below which the effects of oxygen deprivation may occur.

3.6 Toxicity of Methanol

3.6.1 Ingestion of Methanol

Methanol, gasoline and diesel fuel are all toxic materials and ingestion, prolonged skin contact and inhalation of vapours create serious problems above certain threshold levels.

Ingestion of gasoline and diesel fuel occurs principally through siphoning of the fuels, but because these fuels have distinctive odour,

are unpalatable and will be regurgitated if swallowed, the incidence of fatalities from ingestion is small (but positive). Although small quantities of methanol are ingested daily in fruits, vegetables and alcoholic beverages, ingestion of as little as 6ml may lead to symptoms of poisoning 12-48 hours later such as visual disturbances, abdominal pain, nausea and vomiting. Doses in the range of 100-250mL can be lethal, although doses as low as 33mL have been lethal. Antidotes can be effective if applied in time, but data from the American Association of Poison Control Centres indicates that 1.5% of the 1,125 methanol exposures reported resulted in a major medical outcome and 0.3% in death. There were 10,456 gasoline exposures reported in the same period, but only 0.1% resulted in a major medical outcome and no fatalities occurred as a result of gasoline exposure.

Methanol could be ingested through fuel siphoning, drinking when mistaken for water or ethyl alcohol, or in water contaminated by an underground spill from a methanol storage tank. The low odour, low taste and absence of colour of methanol increases the ingestion hazard relative to gasoline and diesel and this issue must be resolved before large volumes of M100 are made available. The gasoline content of M85 is expected to sharply reduce the possibility of ingestion. Other measures could be the addition of parts per million of odourants (e.g. mercaptans similar to those added to natural gas and LPG), dyes and bitter-tasting materials similar to those used in the past to denature cooking alcohol.

3.6.2 Skin Contact

Use of gasoline as a solvent and frequent contact with it at refuelling stations is to be avoided as prolonged skin exposure can cause dermatitis and skin blistering. Similar exposure to liquid methanol is more hazardous as methanol can be absorbed through the skin and is only slowly metabolized so that toxic effects can be compounded by repeated excessive exposures to the point where toxicity effects are

possible. It is considered likely, but not proven, that M85 would be at least as hazardous as M100, because the gasoline content could accelerate methanol adsorption by defatting the exposed skin tissue.

3.6.3 Inhalation

Inhalation of fuel vapour is a potential hazard to drivers (vehicle exhaust, evaporative and refuelling emissions), to fuel industry employees and to those engaged in spill clean-up and fire-fighting. The hazard is directly related to the concentration of the fuel in air, and the duration of the exposure. Exhibit 3.11 provides estimates of the tolerance for methanol vapour over time. Much more conservative levels have been selected in industrial health legislation. The levels established for gasoline and methanol in the workplace are summarized in Exhibit 3.12.

The short-term (15 minute) exposure level (STEL) for gasoline has been established by Canadian and U.S. health and safety authorities at 500 ppm in air and the threshold limit value (TVL) at 300 ppm is considered a safe level of exposure over an 8-hour work day. The low levels have been set to provide protection, not only against the effect of gasoline hydrocarbons on the respiratory tract and nervous system, but also against the particularly toxic and cumulative effects of benzene which may be present at up to 15% levels in gasolines. Although diesel fuel vapours are toxic, the low volatility of the fuel, except in fire, reduces the possible exposure.

Methanol vapour is judged to be more toxic than gasoline at high concentrations. As previously noted, the vapours are life-threatening at concentrations above 25,000ppm in air and toxic effects are noted at 3,000ppm. The STEL has been set at 250ppm and the TVL at 200ppm to provide a wide margin of safety in the workplace. Concentrations above these levels are unlikely to be encountered except in cases of equipment failure and in unventilated mechanics' pits and during methanol fires

Exhibit 3.11

Estimated Tolerance Values for Methanol Vapour

	ppm in air
SINGLE BUT NOT REPEATED EXPOSURE	
1 hour	1,000
8 hours	500
24 hours	200
5x8 hour working days	200
168 hours	50
30 days	10
60 days	5
90 days	3
SINGLE OR REPEATED EXPOSURES	
1 hour out of every 24 hours	500
1x2 hour or 2x1 hour every 24 hours	200

Source: U.S. Advisory Center on Toxicology

Exhibit 3.12

Health Hazard Exposures for Methanol and Gasoline

	Gasoline	M100
Vapour inhalation		
Short-term exposure level(STEL) ppm in air	500	250
Threshold limit value (TLV) ppm in air	300	200
Ingestion of Liquid		
Minimum lethal level of ingestion, ml	Not retained	30

STEL measured over 15 minutes

TLV measured over 8 hours

where dense vapours may accumulate. The STEL is a guideline for fire-fighters and spill decontamination squads who should use self-contained breathing apparatus if ventilation or water spray cannot reduce the concentration below the recommended maximum exposure levels.

The risk to the public from methanol vapour exposure in vehicle operation or refuelling is negligible. The toxicity of M85 vapour and a recommended exposure standard have not been established. Work should be undertaken to develop this information and to ensure that there are no synergistic effects between the methanol and gasoline components. Attention should also be given to establishing the maximum level of aromatics which should be incorporated in M85 for flame luminosity.

4. INCIDENT DATA

4.1 Sources of Incident Statistics: Spill and Fire Data

Spills of oils, petroleum products and other hazardous materials (including methanol) in excess of 100kg are monitored and reported by Environment Canada. Special analyses of methanol and gasoline spills were prepared for this investigation by Environment Canada and the U.S. Department of Transportation. Data on petroleum product spills in the U.S. was obtained from publications of the American Petroleum Institute and citations of methanol spills in Europe and N. America from the Industrial Safety Branch of TNO in the Netherlands and a literature survey.

Data on fires due to petroleum products is not available from a central source. Transport fuel fire data can be deduced from some of the spill data and from provincial government agencies, such as the Fire Marshals' Offices and various vehicle and vehicle fuel safety agencies. These agencies, however, have different record-keeping practices and classifications for fuels which limit the extent to which generalizations can be made on fuel safety.

While gasoline fire data can be obtained from these records, diesel fuel fires are not distinguished from fuel oil or other combustible liquid fires, and methanol fires are included in other categories.

Comparison of the data for methanol and gasoline is compromised by the fact that the methanol data reflect the production, storage and transportation of methanol for chemical uses and export rather than for domestic vehicle fuel purposes, and the low volume of methanol involved in comparison with gasoline. The differences in the location of spills are expected to disappear when vehicle fuel becomes a dominant use for methanol.

Data on petroleum incidents is sufficient to allow tenuous correlations to be made between spill and fire data in selected circumstances so that historic data on the frequency and volume of spills may be used to impute frequency of fire and the possible outcome in terms of casualties and damage. This is the basis for risk assessment studies. It is too early in the history of methanol fuel to draw such correlations and accordingly we restrict the analysis of methanol safety to a comparison of methanol and gasoline spills and, in Section 5 and 6, to comparative estimates of the safety of these fuels at important points in the transportation and distribution system based upon spill data and correlations already drawn (Section 3) between safety and fuel properties. Exhibit 4.1 provides a schematic view of the nodes in the fuel transportation and distribution system where spills occur.

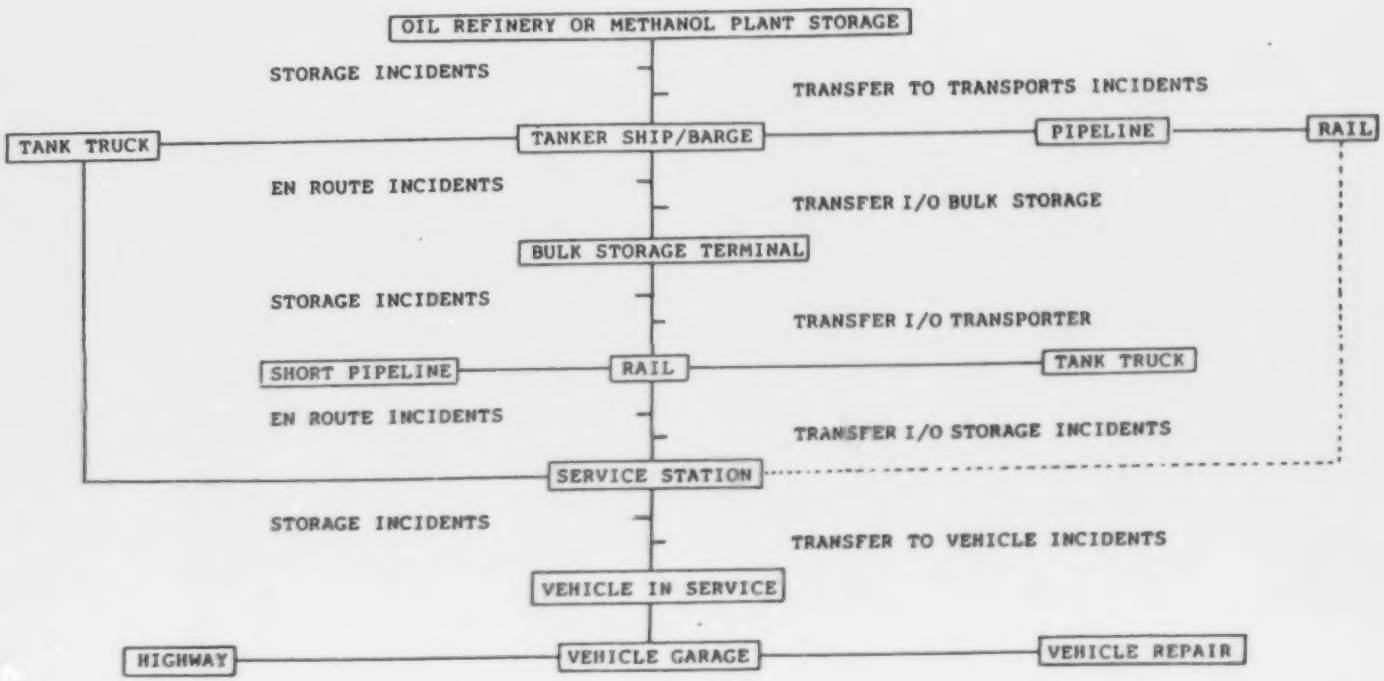
4.2 Spills of Oil, Gasoline and Methanol in Canada

Over the 10-year period 1973-84 Environment Canada data shows that:

- the petroleum and transport sectors accounted for 58% and 16% respectively of all reported spills
- oil and gas-related spills are, as expected, dominated by crude oil spills (40% of petroleum spills), by spills of #2 fuel oil (diesel, jet fuel, kerosene and home heating oil, 21% of spills) followed by gasoline (13% of petroleum sector spills)
- gasoline spills account for only 3% of the tonnage of spills in this sector or 7% of the sector if gas condensates are excluded
- industrial chemicals account for 19% of spills in the non-oil and gas sector (or 40% if spills of saline water are excluded)
- methanol was ranked the 19th most frequently spilled chemical, a substantially lower frequency of spills than for a number of highly reactive chemical hazards such as sulphuric acid, ammonia, chlorine and hydrogen sulphide.

Exhibit 4.1

Safety Nodes In Fuel Distribution System



FUEL OPERATIONS WITH SAFETY: 10 IN/OUT FUEL TRANSFERS
3 TANK STORAGE
2 FUEL EN ROUTE
VEHICLE USE AND VEHICLE STORAGE

Environment Canada recorded 568 gasoline and 22 methanol spills in the 5-year period 1982-86. The location, frequency and size of methanol and gasoline spills are summarized in Exhibit 4.2.

The causes of spills were similar in the case of gasoline and methanol (Exhibit 4.3) involving truck overturns, collisions, leaks from piping and tanks, overfilling tanks and malfunction of valves and fittings. These were occasioned in both cases by human error, material failure, weather and road conditions.

4.3 European Data

The Dutch group TNO maintains a databank on incidents with hazardous materials which provided a summary of 49 methanol incidents, principally of European origin, reported in the period 1969-86. Distribution of these incidents by location is summarized in Exhibit 4.4. As with historic Canadian data, transportation of methanol was a more frequent source of spills than leaks from stationary sources during manufacture, storage and transfer (transhipment). This contrasts with the spills of gasoline which are dominated by spills at service stations - not yet a significant location for methanol.

Exhibit 4.5 summarizes the results of an in-depth study of gasoline incidents in Europe developed by TNO in the Netherlands and used in a comparative assessment of the risks involved in storing and distributing gasoline and propane. The data and risk assessment methodology was adopted in the comparative risk assessment of methanol and gasoline, the results of which are presented in Section 5.

Exhibit 4.2

Frequency of Major Spills of Gasoline and Methanol in Transportation, Distribution and Storage

		Frequency % Spills in Sector	Average Volume/Spill (cubic-metres)	
GASOLINE				
STATIONARY SOURCE				
Service station	HIGHEST	35.0	9.8	
Bulk storage	HIGH	19.0	190.0	
Other storage	MEDIUM	9.5	2.7	
Refinery	LOW	0.2	6.8	
TRANSPORT OF FUEL				
Tank truck	HIGH	20.5	12.1	
Other truck	LOW	2.1	1.6	
Train	LOW	1.8	13.6	
Pipeline	LOW	1.1	7.0	
Major pipeline	LOW	0.2	2420.0	(1 in 1985)
Marine	LOW	0.7	12.1	
Inland barge, tanker	LOW	1.2	14.8	
Other water	LOW	0.7	54.5	
METHANOL				
STATIONARY SOURCE				
Storage		4.5	31.2	
Refinery		4.5	16.4	
Chemical plant		4.5	36.0	
TRANSPORT OF FUEL				
Tank truck		50.0	10.5	
Train		22.5	18.7	
Pipeline		4.5	1.3	
Water craft		4.5	9.8	

Source: Environment Canada data for 1982-6 reworked
568 gasoline & 22 methanol spills recorded

Exhibit 4.3

Fuel Spills in Canada 1982-86: Causes and Reasons

GASOLINE		METHANOL	
RANK	CAUSE	RANK	CAUSE
1	Tank leak	1	Truck overturn
2	Overflow	2	Derailment
3	Pipe leak	3	Valve, fittings
4	Valve, fittings	3	Collision
5	Truck overturn	5	Discharge
6	Discharge	5	Other accident
7	Unknown	5	Pipe leak
8	Other accident	5	Tank leak
9	Collision	5	Overflow
10	Container leak	5	Other
11	Derailment		
12	Sinking		
13	Grounding		
13	Crash		
13	Other		
	REASON		REASON
1	Human error	1	Unknown
2	Unknown	2	Human error
3	Corrosion	3	Ice frost
4	Equipment failure	3	Material failure
5	Material failure	3	Other
6	Ice frost	6	Storm, flood
7	Vandalism	6	Road condition
8	Other	6	Overstress
9	Gasket, join	6	Earthquake
10	Damage by equipment		
10	Road condition		
12	Overstress		
13	Storm, flood		
14	Intentional discharge		
15	Subsidence		
15	Weld + seam failure		
17	Power failure		
17	Fire, explosion		
17	Earthquake		

Exhibit 4.4

Methanol Incident Location: TNO Database 1969-86

	FREQUENCY OF SPILLS % REPORTED	PRINCIPAL SOURCES
STATIONARY FACILITIES		
Storage	6	Lightning, vandalism
Transhipment	6	Tank overflow, equipment failure
Manufacture and conversion	20	Leaks from vessels, pipes, vales, fire
End use	2	Misuse of methanol
SUBTOTAL	34	
TRANSPORTATION		
Sea	2	Ship collision
Inland waterway	22	Collision and grounding of tankers, fire on vessel
Rail	14	Derailment, tank leaks, valve leaks, collision
Road	27	Collision, overturn, equipment failure
SUBTOTAL	65	

Source: "FACTS" Database search, TNO, The Netherlands

Exhibit 4.5
Estimates of Gasoline Spills

LOCATION		CAUSE OF SPILL	FREQUENCY OF OCCURRENCE	SIZE OF SPILL
REFINERY	Stationary situation	overfilling storage tank	once/160,000 yrs	82 kg/sec
		escape from a manhole	once/59,000,000 yrs	448,350 kg
BULK STORAGE DEPOT	Stationary situation	escape from a manhole	once/114,000,000 yrs	2940,000 kg
		escape from tank in tank basin	once/100,000 yrs	240 kg/sec
	Transshipment to a tank truck	failure of tank truck: aluminium	once/2,000,000 yrs	35,000 kg
		failure of tank truck: sheet-steel	once/2,000,000,000 yrs	7,400 kg
		overfilling compartment	once/250 yrs	12 kg/sec
SERVICE STATION	Stationary situation	no undesirable events		
	Transfer from tank truck	truck failure (fire): aluminum	once/550,000 yrs	35,000 kg
		truck failure (fire): sheet steel	once/55 billion yrs	7,400 kg
		escape from truck	once/8.3 yrs	23 kg/sec
	Transfer to car	See vehicle incident analysis		
GASOLINE TANK TRUCK	On highway	broken pipe/hole in tank wall	once/6,000 yrs	23 kg/sec
		instant release of tank contents	once/3,000 yrs	>7.5 m3

Source: TNO, LPG, A Study, prepd for Netherlands Min. of Housing, Physical Planning and the Environment, 1983.

5. SAFETY AT SERVICE STATIONS, BULK STORAGE TERMINALS AND GARAGES

5.1 Service Stations

The changes required in equipment and practices as methanol fuel is introduced at service stations are modest and incremental compared to the extensive changes needed for propane and compressed natural gas.

5.1.1 Gasoline Spill and Fire Experience

Although fleet depots for trucks and buses dispense diesel fuel, the majority of public and private service stations are essentially locations where gasoline is dispensed: propane, CNG and diesel fuel together being only a minor component of the fuel market for automobiles and light-duty trucks. It is not surprising, therefore, that service stations are the most frequently cited sources of gasoline spills (35%) and that fires due to gasoline account for about 40% of all fires at service stations. Canadian data is similar to that at U.S. service stations, summarized in Exhibit 5.1. (See also Appendix). Fires in vehicles account for about 60% of the fires at service stations, the remainder being structural fires, the majority of which are not caused by gasoline or other fuels.

The gasoline spill record at Canadian service stations is excellent. In the period 1980 to early 1987 the average annual rate of reported incidents at public and private service stations totalled 115 - about one incident for each 200 locations, one for each 113,000 gasoline-powered vehicles in service in the year or one incident for each 233 million litres of gasoline sold.

As illustrated by Ontario data (Exhibit 5.2), 45% of gasoline spills reported at service stations in the period 1980-87 arose from a single source - leaking underground storage tanks (LUST). The frequency of LUSTs peaked in 1983. A tank replacement program initiated by

Exhibit 5.1

U.S. Public Service Station Fires 1980-84

(Annual Average of Fires Reported to Fire Departments)

Structure Fires	Fires	Civilian Deaths	Civilian Injuries	Direct Property Damage
All structure fires	1,580	1.0	55.6	$8,880,000
Any gas or liquid - first item ignited	570 (36.1%)	1.0 (100%)	52.4 (94.2%)	$5,440,000 (61.3%)
Gasoline	387 (24.5%)	1.0 (100%)	39.2 (70.3%)	$3,850,000 (43.3%)
LP gas	6 (0.4%)	0.0 (0%)	2.0 (3.5%)	$ 110,000 (1.2%)
Class II liquid	62 (3.9%)	0.0 (0%)	0.4 (0.7%)	$ 130,000 (1.5%)
Any item first ignited other than gas or liquid	(63.9%)	(0%)	(5.8%)	
Paper	(16.8%)			(38.7%)
Sawn wood	(7.7%)			(4.3%)
Rubber	(-5.4%)			(12.9%)
Unspecified known	(3.7%)			(2.5%)
Unknown-type plastic	(3.6%)			(1.8%)
Cardboard	(3.1%)			(0.8%)
Cotton, rayon	(3.0%)			(2.6%)
				(0.3%)
Vehicle Fires				
All vehicle fires	2,100	1.6	39.6	$1,900,000
Gasoline (first item ignited)	1,020 (48.4%)	1.0 (63.0%)	26.9 (68.0%)	$1,000,000 (52.5%)
LP gas (first item ignited)	10 (0.5%)	0.0 (0.0%)	2.3 (5.9%)	$ 32,000 (1.7%)
Class II liquid (first item ignited)	11 (0.5%)	0.0 (0.0%)	0.0 (0.0%)	$ 14,000 (0.7%)
Automobile	1,510 (71.6%)	1.0 (63.0%)	18.0 (45.5%)	$1,130,000 (59.8%)
Tank truck - flammable or combustible liquid	8 (0.4%)	0.0 (0.0%)	0.0 (0.0%)	$ 1,300 (0.1%)
Tank truck - LP or compressed gas	1 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	$ 2,100 (0.1%)

Notes: All estimates are based on fire department data reported to the NFPA annual stratified random sample survey and the U.S. Fire Administration's (USFA) National Fire Incident Reporting System (NFIRS), combined using statistical methods developed by analysts at NFPA, USFA, and the Consumer Product Safety Commission.

Analyses do not include private or marine service stations, whose annual average structure fire experience in 1980-84 was 13% of the structure fires in public service stations.

Class II combustible liquids are defined by flashpoint and include kerosene, diesel fuel, and nos. 1, 2, 4, and 5 fuel oil.

All figures are expressed to two or three significant places.

Source: U.S. National Fire Protection Association

Exhibit 5.2

Gasoline Incidents at Service Stations (Retail and Private) Ontario 1980-87

	1980	1981	1982	1983	1984	1985	1986	1987 (1)	TOTAL
# Incidents	39	27	58	76	38	35	48	43	364
# Incidents ex LUST (2)	17	10	25	39	15	23	34	39	202
Fires	3	2	2	4	2	3	2	2	20
Explosions	1	1	3	0	0	0	0	3	8
Injuries	0	1	3	1	0	3	0	1	9
Fuel Used (millions litres/yr)	11900	11857	10990	10842	11015	11196	11323	5700	84823

(1) 1987 - 6 months only
(2) L.U.S.T. = Leaking Underground Storage Tank

Source: Data from Fuels Safety Branch, Ontario Ministry of Consumer and Commercial Relations

industry in 1984 has since reduced the rate and the replacement program continues. No casualties were reported from the LUST incidents, but the volume of gasoline spilled in these incidents is large and clean-up costs, including gasoline recovery, can be substantial as illustrated in Exhibits 5.3 and 5.4.

The highest volume per spill in incidents at service stations occurs in discharges/spills from road tankers not from LUSTs, but these tanker incidents at service stations are rare. The available data shows that 3% of spills at service stations involve road tankers. Leaks from overfilling of tanks, pipes, valves and fittings occur more frequently (see Exhibit 5.5 for Canadian data).

A survey of fires and casualties at service stations attributed to gasoline was conducted in the major gasoline-consuming provinces of Canada (Ontario, Quebec, British Columbia and Alberta), and in the U.S. The conclusions are:

- There are substantial differences in the number of incidents of gasoline spills reported in each province: the size of a spill considered worthy of reporting varies.

- Taking Ontario's experience in 1980 to early 1987 as an example (see Exhibit 5.6), fires occur in 5-6% of the total incidents reported and 10% of the cases where aboveground spills occurred. Explosions accompanied about 4% of the aboveground spills and fire-burn injuries in about 4% of the aboveground spills. No fatalities due to gasoline refuelling at public and private stations were reported in the period. About 30% of the injuries in Ontario involved a member of the public.

- U.S. service station fire and casualty data in the period 1980-84 purchased from the NFPA indicates that injuries were experienced in 4.7% of gasoline fires, and fatalities in 0.14% of these fires.

Exhibit 5.3

Frequency and Magnitude of Gasoline Spills in Quebec 1981-86

	# CASES	LITRES SPILLED	LITRES RECOVERED	% OF FUEL LOST
Leaks	420	1509481	662513	56.1
Discharge/spill - operator error	117	548159	269726	50.8
Discharge/spill from road tanker	26	274391	60866	77.8
Fires, explosions (1)	30	53137	20000	62.4
Other incidents	364	193731	179614	7.3
Total	957	2578899	1192719	53.8

(1) Fires per 100 leaks = 3.1

Source: Fire incident data, Quebec Ministry of Energy and Resources

Exhibit 5.4

Gasoline Service Station Spill Data Quebec

CAUSES OF SPILLS	AVG SIZE OF SPILL (litres)	COST OF DAMAGE AND FUEL RECOVERY ($)
Defective equipment	3600	16030
Employee error	4700	3360
Road tanker incidents	10500	38800
Fires, explosions	1770	77090
Other spills	530	4730
All spills averaged	2700	12700

Source: Quebec Ministry of Energy and Resources. Data for 1981-86.

Exhibit 5.5

Cause Profiles for Fires at Gasoline Service Stations

CAUSES OF SPILLS/INCIDENTS

Canada	%	Ontario	%
Tank leak	40.0	L.U.S.T. (Leaking Underground Storage Tank)	46.5
Overflow	19.5	Piping leak	28.6
Pipe leak	16.0	Other	8.6
Valve fittings	11.5	Tank overfill	5.9
Discharge	6.0	Dispenser malfunction	4.6
Unknown	3.0	Tanker delivery spill	2.7
Other accident	2.5	Accident with vehicle	3.0
Other	1.0		
Collision	0.5		
Total Spills/Incidents	200	Total Spills/Incidents	370

CAUSES OF FIRES

Structural Fires	%	Vehicle Fires	%
Other equipment	34.1	Human failing	29.4
Electrical distribution	18.0	Misuse of material ignited	23.5
Match, ligher, other open flame	10.7	Mechanical/electrical failure	17.7
Heating equipment	9.8	Arson or set fire	17.7
Incendiary or suspicious	9.7	Vehicle accident	11.7
Other heat source	5.0		
Unknown	4.1		
Smoking materials	2.5		
Appliances, tools, air conditioning	2.3		
Natural causes	2.1		
Other (exposure, cooking equipment)	1.7		

Sources: Environment Canada special computer analysis of spills
Ontario gasoline fuel station data - Fuels Safety Branch, MCCR
U.S. NFPA special analysis of fire data
British Columbia vehicle fire database

Exhibit 5.6

Gasoline-Related Incidents Reported

at Public and Private Service Stations in Ontario 1980-87

Aboveground leaks	202
LUSTs	164

Incidents as % Aboveground Leaks

Fires without explosions	8
Total fires	10
Explosions with/without fires	4
Fire burn injuries	4
Other injuries	0.5
Fatalities	0

Source: Data from Ontario Fuels Safety Branch

5.1.2 Methanol Fuel Safety Projections

The high volume of methanol and its aggressive behaviour to metals and plastics indicate that spills of methanol may be expected to be more frequent that those of gasoline and diesel fuel. Service station operators are now more aware of the problems of corrosion and damage to underground tanks and equipment. Legislation is in place requiring the monitoring of corrosion and fuel loss in underground storage vessels.

Storage tanks compatible with methanol and resistant to corrosion are clearly a requirement. Fibreglass tanks constructed from methanol-resistant resins are available from manufacturers; double-walled metal storage tanks with appropriate corrosion protection (cathodic protection devices or coatings) are alternatives. Small underground methanol spills are likely to be readily diluted by ground water and degraded over time by bacterial action and therefore present a less serious environmental and safety hazard than gasoline or diesel fuel. Large underground spills of methanol will still require clean-up to reduce the likelihood of methanol contamination of drinking water in the vicinity of the service station.

Migration of underground gasoline spills along the water table presents a more serious hazard, since the water-insoluble fuel will not be diluted and may not only contaminate drinking water but also migrate to basements where the vapour may be ignited by furnaces or other sources.

The major problem with underground spills of methanol arises from the low odour and lack of colour of the water-soluble fuel. This can be overcome by the addition of a suitable dye to M100 or by use of M85. With M85 the gasoline component will separate out in wet soils and generate the same fire hazard as in a gasoline spill.

Provincial regulations, such as the Ontario Energy Act, require owners of tanks and pipeline to ensure that:

- any leaks are repaired
- any defective equipment is replaced or repaired
- all reasonable precautions are taken to prevent escape or spills of fuels.

NFPA Code #329 "Underground Leakage of Flammable and Combustible Liquids" provides an excellent starting point for the development of

practices and equipment specific to the handling of M100 and M85. Methanol fuel-specific instructions are required which would include modifications on inspection, detection, containment and clean-up practices to reflect the water solubility of methanol, the absence of odour, and the low visibility of methanol spills. It is noted that the Draft Specification of Canadian Commercial Fuel Methanol produced by the Canadian General Standards Board (see Appendix) which specifies M83-M88 as the composition contains the statement:

> "4.2 Colour: May include a dye in accordance with standard practice for purposes of product identification."

It is suggested that addition of a dye to M100 and also to M88-M83 be made mandatory to facilitate detection of liquid spills and contamination of underground water.

5.1.3 Other Storage Tank Considerations at Service Stations

The Ontario Gasoline Handling Act and Gasoline Handling Code is typical of the provincial regulations in Canada regarding the storage of gasoline and other Class 1 liquids (such as methanol). It also deals with Class 2 liquids (diesel).

The Ontario regulation limits the size of an underground storage tank for Class 1 liquids to 10,000 imperial gallons (40,546 litres) and the total volume on site to twice that amount. 50,000 gallons, however, is allowed for diesel fuel. The volume limitation on underground storage tanks may need to be changed in the future to accommodate the larger volumes of M100 or M85 needed to service vehicle fleets.

In Ontario the maximum volume of Class 1 liquid which may be stored aboveground at service stations is limited to 45 gallons.

The wide flammability range of M100 will require that flame

arrestors be installed in the vent pipes and fill spouts of M100 fuel tanks: these are already used at chemical plants. The same factors will require that during refuelling of the bulk storage tank the vapours be collected and recovered (similar to current "Stage 1" refuelling emission control in effect in California for gasoline). As with gasoline, the tanker must be grounded during fuel transfer to the storage tank to prevent the build-up and discharge of static electricity. Splash blending and overhead filling of fuel tanks is not recommended, since these processes can build static charge which is important even with methanol fuels because of the wide flammability range, despite the high electrical conductivity of M100 and presumably M85 (not yet measured, however). Increased rate of fuel transfer may be needed to overcome the volume effect of low energy density methanol fuels and this increases the rate of static charge build-up.

5.1.4 Aboveground Facilities at Service Stations

The major risks at gasoline service stations have been quantified in extensive risk assessment studies conducted by the Industrial Safety Branch of TNO in the Netherlands, using existing incident data on the size and frequency of spills, "fault-tree" analysis of component failures such as hose, piping, valves, tank walls and collision, corrosion, overfilling and other causes of spills, and the frequency with which those spills lead to fire and injury.

The principal risks at gasoline service stations (with underground fuel storage) were associated with:

- escape of gasoline from road tankers due to accidents on site or failure of the tank and transfer lines which produced a stream of gasoline averaging 21-23kg/second
- tanker failure due to fire or puncture of the tank wall when the entire contents of the tanker may be released over a short period (the standard aluminum gasoline tank on the vehicle is more

vulnerable than a steel tank and the volume of the aluminum tank is normally higher than that of a steel tank; quantities discharged in these scenarios have been calculated to be 35,000kg and 7,400kg respectively)

- escapes from the fuel hose delivering product from the dispenser to the vehicle occasioned by vehicle driveaway while still coupled to the dispenser or other hose failures.

These high-frequency incidents were found to produce a small stream of gasoline: 1kg/second being the average rate.

The effect and damage distance resulting from these spills provided the casualty and damage effect distances given in Exhibit 5.7.

The failure of the road tanker in the circumstances considered frequently leads to fires (6.5% of spills ignite in this scenario) with a pool radius of 20 metres within which fatalities would be 100% and a radiation damage area surrounding the burning pool in which fatalities would exceed 1% with a radius of 80 metres. This corresponds to radiant heat at the perimeter not less than 7.5kw/sq.metre. The frequency of such incidents is rare (once in 55 million years at any one station).

The higher frequency spills from the vehicle dispenser have incidents with a much lower fatality rate: 100% fatalities being expected in fires that occur within 1 metre of the spill and 1% up to 5 metres from the spill.

When the risk assessment is conducted using the same quantity of M100 and M85 at the service station substantially lower casualty and damage areas are found outside the liquid pool fire area.

The comparative assessment of M100, M85 and gasoline is also summarized in Exhibit 5.7.

Exhibit 5.7

Maximum Distance and Effect of Fire Incidents

	Spill Volume	Frequency of Occurrence/Year	CASUALTY AND DAMAGE DISTANCES (METRES) 100% Fatality (In Pool)		1% Fatality (Radiation)
Escape from hose at refuelling	1.25 litres/sec	0.05	Gasoline	1	5
			M100	1	1.5
			M85	1	1.7
Tank truck failure (internal failure or impact)	2.5 litres/sec	0.13×10^{-7}	Gasoline	9	35
			M100	9	12
			M85	9	14
Tank truck failure (fire) Aluminum tank (ALUMINUM NOT USED FOR METHANOL TANKS)	45,000 litres	0.18×10^{-7}	Gasoline	20	80
Steel tank	9,500 litres	0.18×10^{-12}	Gasoline	20	80
			M100	20	25
			M85	20	29
Escape from tanker	30 litres/second	0.12×10^{-2}	Gasoline	10	40
			M100	10	13
			M85	10	15

Parameters for "Standard" Station

	Throughput tonnes/yr:m3/yr	Transhipments/yr #	Fuel Transfer Time minutes	Transfer Speed m3/hr
Transhipment from road tanker	500:685	15	30	110
Automobile fill-up	500:685	17,000	1	2.5

Storage capacity underground = 12-50m3
Road tank truck capacity = 48 m3, compartmentalized

Source: TNO Risk Assessment Study

Even when allowance is made for a possible higher throughput rate for M100 and M85 than gasoline, the safety improvement achievable through conversion to methanol fuels is highly significant, since the area exposed to potentially fatal radiant heat damage is over an order of magnitude lower with M100 and M85 than with gasoline. The differences that exist between the area exposed to high radiation damage with M85 and M100 are less dramatic, but M100 will be the preferred fuel from the point of view of fire injury and property damage at service stations.

A combination of the frequency of incidents at a given service station with fatality data can be used to prepare individual risk assessments. Exhibit 5.8 provides a comparison of the risk of fatality to an individual located at varying distances from the source of a major leak of gasoline or M100. The risk assessment can be extended to provide estimates of the risk to communities located with the potential fire area when the site and population density are defined.

5.1.5 Other Measures Required at Service Stations

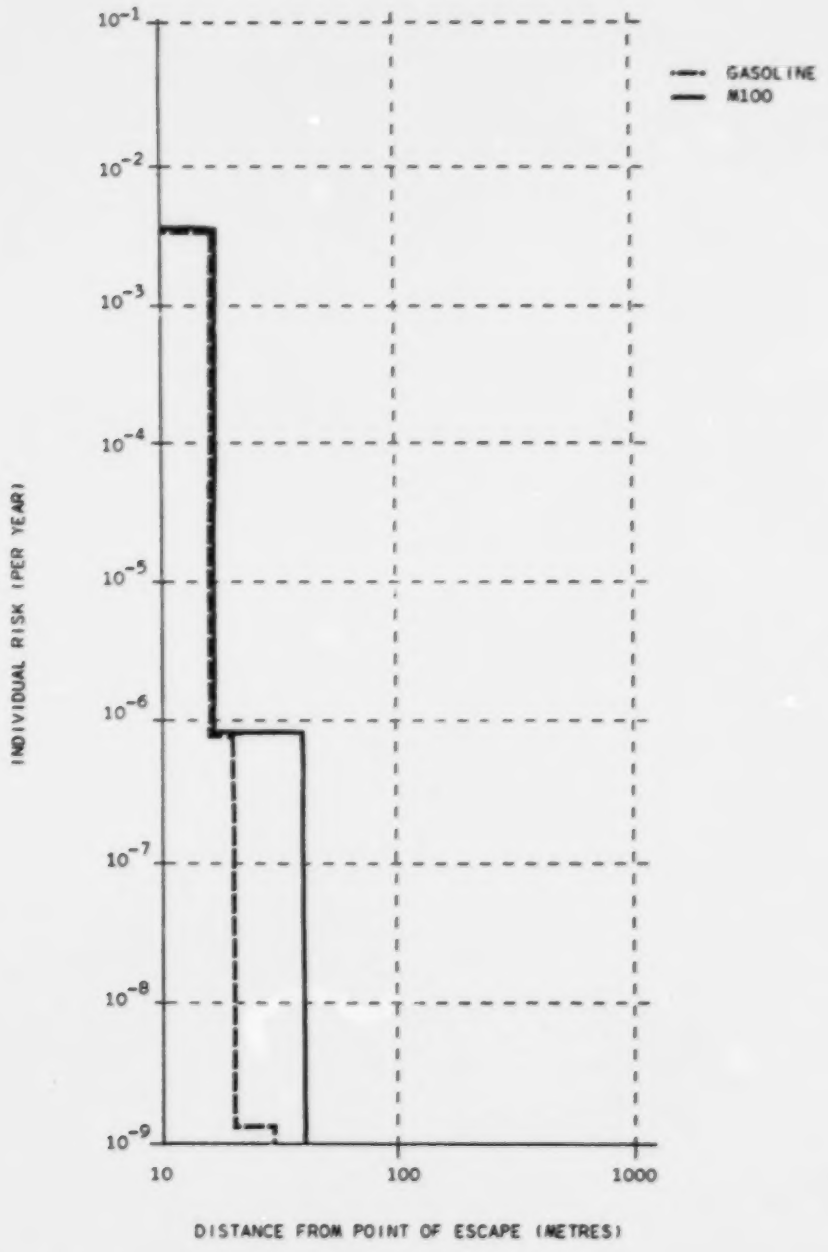
In addition to the fire safety, environmental and health control measures required for dispensing gasoline, precautions must be taken with M100 and M85 to minimize health hazards and to provide methanol-compatible equipment and practices. Exhibit 5.9 provides a list of commonsense but important items that are needed when handling methanol.

5.1.6 Improvements at Service Stations

The key items requiring attention to improve service station safety are:

Exhibit 5.8

Comparative Risk at Service Stations Dispensing Gasoline and M100



Notes: (1) Individual risk is the probability (or frequency) of a person being killed as a result of a fire incident at a service station
(2) The throughput for both fuels is 500 tonnes per annum

Source: Bruggeman, J.M., "Risks of Methanol Filling Stations," risk assessment study prepared for R.F. Webb Corp., TNO Division of Technology for Society, Apeldoorn, The Netherlands, Feb. 1988

Exhibit 5.9

Risk Reduction at Methanol Service Stations

FIRE SAFETY EQUIPMENT AND PRACTICES

Employee Training, Awareness

1. Train employees in spill avoidance, spill and fire containment. Provide manuals and videos.
2. Ensure vehicle engines are not running during refuelling.
3. No smoking during refuelling or other exposure to methanol.
4. Do not overfill vehicle tank. Replace filler cap after filling.
5. Ensure vehicle/dispenser hose are disconnected after vehicle filling.
6. Avoid welding, grinding and generating sparks and open flames in refuelling areas.

Equipment

1. Store methanol only in approved bulk storage tanks.
2. Install methanol fire detection systems until luminous burning grades are commercialized.
3. Install vapour recovery equipment at busy stations.
4. Use ABC dry chemical fire extinguishers for small methanol fires. Stock alcohol-resistant foam extinguishers when large volumes of methanol are involved.
5. Install flame arrestors on storage tanks and in fuel tanks of large vehicles.
6. Use non-sparking tools.
7. Use appropriate equipment and materials in construction of stations (see Appendix for recommended list).

EMPLOYEE HEALTH

1. Train employees in the procedures to be used in handling methanol. Provide training aids, reminders.
2. Avoid prolonged inhalation of vapour.
3. Do not use methanol as a solvent for cleaning tools, parts or hands.
4. Do not siphon methanol fuel or swallow it.
5. Learn safety procedures in event of skin or eye contact. Seek medical attention immediately.

- complete the development of fuels with persistent flame luminosity
- develop systems to detect flames from M100
- prepare methanol-specific material for the training of station personnel and fire-fighters
- initiate training programs for staff before a community adopts methanol fuel
- make a survey and conduct tests of the safety of methanol storage tanks and designs to minimize fire and explosion hazards.

5.2 Bulk Storage Terminals

Bulk storage incidents account for 28% of the reported gasoline spills in Canada, but only 10% of the methanol spills; this suggests that the equipment and practices in the chemical industry may be more stringent than those in the petroleum industry and should not be relaxed in the conversion of depots to handle fuel methanol.

The bulk storage facilities may be located at the manufacturing plant or at pipeline, rail, road tanker, barge and ocean tanker terminals. Very large volumes may be stored and transferred at high speed. Methanol shipments in ocean tankers range up to 50,000 tonnes, barges may carry 3,000 tonnes, road tankers 35 tonnes. The high speed and volumes transferred to and from the bulk aboveground methanol storage tanks and the loading and unloading of mobile storage tanks in vehicles, road and rail tankers increase the potential for pump, valve and pipe failure, overfilling of tanks and creation of static charge. The air close to the inevitable spills that occur may reach levels where fires are ignited and where the employee exposure to vapour can exceed safe levels. The vapour emissions will be increased at locations where M85 is produced by blending with gasoline, particularly if splash blending into tanks is inadequately controlled.

The frequency and volume of spills at bulk terminals is recognized and special precautions and equipment are used, staff are trained in

emergency procedures and strict government regulations applied.

The size of storage facilities for methanol varies according to the location and demand. Currently the largest storage facilities are at chemical plants and bulk export terminals (20,000 tonne tanks). The average spill from these facilities in Canada has been 31-36 tonnes (39m3-45m3). Smaller spills have been encountered at the smaller storage facilities, such as those at refineries where product is stored for use in blending in small volumes into gasoline. The average size of spills from these sources in Canada has been about 16 tonnes (20m3).

In the period 1982-6 Statistics Canada data shows the average size of spills at bulk gasoline terminals to be substantially higher than those reported for methanol (gasoline spills averaged 190m3), but smaller at refineries (6.8 m3 average gasoline spill at refineries). As methanol fuel use grows, the size of shipments will increase, and the size of bulk storage terminal spills and the severity of fires will increase accordingly.

The properties of methanol compared to gasoline lead to the same conclusions for bulk terminal storage as for service stations. The risk from methanol fires will be substantially lower than those from gasoline fires. The area in which fatalities may occur to a 1% frequency among exposed employees will be an order of magnitude lower than for gasoline spills of a comparable size. The area of 1% fatality risk exposure in a 45m3 methanol spill is estimated at 1,250 sq. metres; that for a comparable spill of gasoline at about 20,000 sq. metres. Even when allowance is made the higher methanol throughput, the difference in fire, casualty and damage risk is significant.

Regulations relating to the volume and spacing between outdoor storage tanks and the separation distance between tanks and property do not distinguish between gasoline (Class 1A flammable liquid) and methanol (Class 1B). Typical volumes required for Class 1 liquid

outdoor bulk tank storage are given in Exhibit 5.10. (Distinctions are made, however, between the volumes of Class 1A and 1B liquids which may be stored indoors).

The regulations which currently apply to the volume and location of outdoor storage tanks for methanol therefore provide a significant safety margin compared to gasoline.

Exhibit 5.10
Examples of Separation Distances Required
for the Storage of Class 1 Liquids

Volume (Imp. gals.)	Minimum Distance Tank to Centre of Dike	Minimum Separation Tank to Building or Property Line (ft.)
Up to 1,000	½ tank height	10
1,001-50,000	10 ft. or ½ tank height	10
500,001-1,000,000	" "	40
Over 1,000,000	" "	50

Source: Gasoline Handling Act and Gasoline Handling Code
Ontario 1985

Other aspects of the NFPA regulations recognize the potential that exists with Class 1B flammable liquids, not present in Class 1A, that the vapour space in the tank may be in the flammable fuel concentration range,and specify flame arrestors, venting devices and fill pipe designs which reduce the possibility of fuel ignition. Inert gas blanketing of methanol storage tanks or the use of floating roof tanks are other ways used to overcome the wide flammability characteristic of methanol.

No requirement seems to exist to change current methanol industry practice, but it will be prudent to conduct a comprehensive risk assessment study to guide future equipment design and regulations for M100 and M85. The information should be used in a review of the adequacy of fuel safety regulations and fuel industry practice. This is especially needed where M100 and M85 storage is to be added to an existing petroleum product storage site and where the blending of methanol and gasoline is undertaken. Means to automatically monitor methanol leaks and to provide luminosity to the methanol flame are also required.

The extensive experience of the methanol industry including safety, training and emergency procedures should be adapted for use by the transport fuel industry.

5.3 Garaging of Methanol Vehicles

Canadian fire data (Exhibit 5.11) shows that 50% of the 260 or so gasoline fires reported annually in Canada at stationary sites occur in residential garages and only about 8% in public parking facilities. Only 11% of gasoline fires occur at vehicle repair shops, despite the many sources of ignition that exist in repair facilities such as welding. Vehicle fires in garages and repair shops represented only 1.5% of all vehicle fires reported and explosions only rarely accompany fires.

Gasoline leaks from vehicle tanks due to failure or overfilling and thermal expansion rarely cause fires in garages because ventilation is sufficient to disperse the vapours formed before the minimum fuel in air concentration necessary for combustion is reached. With large spills the concentration of gasoline in air may rapidly pass through the narrow flammable range before an ignition source is contacted. Fires and explosions due to gasoline are most frequently caused by open storage of the fuel or its use as a solvent where gasoline vapours accumulate in drains or unventilated pits before locating an ignition source.

Exhibit 5.11

Gasoline Vehicle Fires at Stationary Sites

	% Total
Service stations, public	12.4
Service stations, private	6.7
Garage, residential	50.6
Parking, public	7.9
Bus, truck, fleet garage	11.2
Motor vehicle repair	11.2

Source: R.F. Webb Corp. database

Fires and explosions have been reported at indoor locations such as chemical plants using methanol. The risk of fires and explosions from the small volume of M100 which will be discharged in unventilated garages is not known and tests of M100 and M85 in the environment are required. There is concern that the fire risk with methanol spilled indoors may be greater than for gasoline, due to the wide flammability range of methanol in air and the accumulation of flammable mixtures in mechanics' pits. It appears from review of the properties of M100 and limited fire data that it is unlikely to be more hazardous from a fire risk viewpoint than gasoline in confined spaces (see Exhibit 5.12).

The health risk from employee contact with the methanol may be somewhat higher than for gasoline. The health hazard from methanol vapours released in hot soak of the engine and in the exhaust will not be as significant as the effect of carbon monoxide from the engine exhaust from vehicles operated in poorly ventilated areas, which exposure is not significantly different for methanol and gasoline.

Exhibit 5.12

Factors Affecting Safety of Methanol and Gasoline in Confined Areas

FACTOR	EFFECT	RANK M100	RANK M85
Low ignition energy of M100	Majority of sources exceed energy for either fuel	+/-	+/-
Wide flammability concentration of M100 in air	Lower level of concentration will be more important than upper range and gasoline will ignite first in most circumstances	+/- to -	+/- to -
Low odour of M100	Spill may be undetected	-	+/-
Low energy content and radiant heat	Temperature above methanol pool lower than gasoline: less structural damage	+	+
Low toxicity and smoke in methanol fire	Reduced fatality rate from asphyxiation	+	+/-
Low flame visibility	Other components in this environment will normally produce adequate smoke	- to +/-	+/-
Toxicity of methanol vapour	Carbon monoxide poisoning from engine in confined areas more toxic than gasoline or methanol	+/-	+/-
Volume of fuel in M100 vehicle increased	Offset by lower energy of combustion of methanol	+/-	+/-

Key: + is less hazardous than gasoline, - more hazardous, +/- equally hazardous

Storage and servicing of methanol vehicles in garages will substantially increase the risk of fire compared to diesel-fuelled vehicles. This is of particular concern because of the anticipated early adoption of M100 or M85 in urban transit buses and the relaxed vehicle fuel handling practices which are feasible with diesel compared to gasoline or methanol. Diesel-fuelled buses are most frequently stored indoors in Canada and are refuelled at the entrance to the garage (while being cleaned). There is no requirement for ventilation of mechanics' pits or installation of flameproof lighting and equipment.

Use of methanol, gasoline or propane in heavy-duty vehicles will therefore require that ventilated repair areas be provided (especially pits), flame-proof equipment be installed where fuel exposures are likely in repair areas, and spark-producing equipment and furnaces be relocated.

Staff training in fuel safety will be required and appropriate signage installed to remind operators and mechanics of the increased hazard associated with the use of Class 1 fuels. The high volatility and toxicity of M100 and M85 compared to diesel fuel will require a higher level of ventilation and health monitoring than now practiced at these facilities. The equipment and practices required are similar to those previously summarized in Exhibit 5.9.

The conclusions on the safety of methanol in enclosed garages are:

- The risk of fire will be substantially greater than in facilities where diesel fuel is used exclusively but not greater than that where gasoline is the principal fuel.
- The risk of adverse health effects on employees from exposure to methanol vapour and liquid is greater than for diesel fuel.
- Garages now used for the storage and repair of diesel vehicles will need to review their operations, safety equipment and

practices before adopting methanol fuel which will be no less extensive than if the conversion were to gasoline.

- Major winter cold-start problems may arise if the decision is made that only outdoor parking is acceptable at certain properties in Canada.
- Vehicle repair areas may need to be equipped with flameproof lighting and electrical fixtures, enhanced ventilation and fire detection equipment.
- Training in methanol fire prevention and fire-fighting will be required, new extinguishers purchased.
- Increased frequency of employee health inspections will be required.
- Signage appropriate to use of a Class 1 flammable liquid will need to be installed in work areas exposed to methanol.
- New means to detect M100 spills and fires are particularly necessary at garages. Use of odourant, fuel dye and a flame luminosity improver for M100 are indicated.
- The ventilation requirements for M100 and M85 vehicle garages and repair facilities need definition.
- Data is needed on the fire and explosion hazard of M100 and M85 fuels in confined areas, including garages and repair shops.

6. SAFETY IN FUEL TRANSPORTATION

6.1 Perspective on Transportation of Methanol

Crude oil and petroleum products dominate transportation world-wide. In 1987 some 41% of all crude oil used was imported: 922.5 million tonnes of crude oil and 286.3 million tonnes of petroleum products were imported and exported between nations, while even larger volumes of crude oil and petroleum products were transported within national borders.

A point of difference between methanol and gasoline or diesel fuel is that economics and logistics require that methanol be transported over long distances from manufacturing plants located close to sources of natural gas to distribution terminals by ship, barge, rail or road tanker. With petroleum it is crude oil which is transported over long distances by ship, pipeline or barge to refineries located close to markets. The volatile and more flammable gasoline is hauled relatively short distances from refineries to terminals and even direct to service stations - most frequently by road tanker. Rationalization of refineries, involving retirement of small units is increasing the hauling distances for gasoline and other petroleum products.

For Canada future supplies of methanol are likely to continue to be from plants located in Alberta and British Columbia, but in the U.S. methanol will increasingly be imported from Canada and by ship from plants in the Middle East, Europe and S. America. Methanol movements in Canada are mainly by surface transport.

6.2 Road and Rail Movements

Detailed analysis of transportation incidents involving methanol and gasoline in the U.S. in the period 1984-87 was provided by the U.S. Department of Transportation's Office of Hazardous Materials

Transportation. Key data is summarized in Exhibits 6.1, 6.2 and 6.3.

The findings are:

- A large number of methanol incidents were reported(329 in 4 years: 26% of the number due to gasoline).
- The number of methanol incidents increased 27% over the 4-year period but the number of major incidents did not.
- No fatalities or injuries were reported (with gasoline fatalities averaged 5/ year, injuries 8/year).
- Only 4.4% of the methanol incidents involved fires or explosions.
- Only 6% of the methanol incidents involved vehicle accidents or derailments (compared to 25% of gasoline incidents).
- A small number of train derailments with loss of methanol from more than one tanker accounted for 50% of the methanol damage estimates (dollars), road tanker incidents were similarly expensive.

The most serious sources of damage were due to:

- external puncture of the tank (loss of contents)
- vehicle accidents and derailments
- human error at loading or unloading (no equipment failure)
- problems with fittings, valves or closures (loose or defective).

The most frequent sources of incidents are attributed to:

- loose fittings, valves or closures (33% of sources cited)
- dropped in handling - small volume spills
- external puncture of tanks (10% of sources cited)
- defective fittings, valves, closures (9% of sources cited).

Exhibit 6.1

Comparison of U.S. (DOT) Methanol and Gasoline Transportation Incidents 1984-87

METHANOL INCIDENTS	TOTAL	DUE TO VEHICULAR ACCIDENTS/DERAILMENTS	% DUE TO VEHICULAR ACCIDENTS/DERAILMENTS
NUMBER OF INCIDENTS	317*	18	5.68
INJURIES - MAJOR	0	0	0
INJURIES - MINOR	0	0	0
DEATHS	0	0	0
DAMAGES (US $)	443,742	407,421	
EVACUATIONS	0		

* ON-HIGHWAY 207; ON RAIL 108

GASOLINE INCIDENTS	TOTAL	DUE TO VEHICULAR ACCIDENTS/DERAILMENTS	% DUE TO VEHICULAR ACCIDENTS/DERAILMENTS
NUMBER OF INCIDENTS	1221	303	24.82
INJURIES - MAJOR	12	10	83.34
INJURIES - MINOR	19	9	47.37
DEATHS	21	21	100.00
DAMAGES (US $)	17,540,038	15,684,208	89.42
EVACUATIONS	2		

Source: U.S. Dept. of Transportation, Office of Hazardous Materials Transportation, 1988

Exhibit 6.2

U.S. (DOT) Methanol Spill and Fire Data

	1984	1985	1986	1987	TOTAL
INCIDENT TYPE					
SPILLS	75	68	79	93	315
FIRES	6	0	5	3	14
TOTAL	81	68	84	96	329
INCIDENTS BY MODE					
RAIL	32	21	28	27	108
HIGHWAY HIRE TRUCK	45	41	50	65	201
HIGHWAY PRIVATE TRUCK	1	0	4	1	6
OTHER	3	6	2	3	14
VOLUMES OF SPILLS (US GALLONS)					
0-10	64	59	67	80	270
11-100	5	5	6	9	25
101-200	0	1	2	3	6
201-500	1	0	0	1	2
MORE THAN 500	10	2	9	3	24

Source: U.S. Dept. of Transportation, Office of Hazardous Materials Transportation, 1988

Exhibit 6.3

Summary of U.S. Methanol Transportation Incidents 1984-87: Failure Analysis

	TOTAL #	INCIDENTS DAMAGE $	INTEGRATED DAMAGE $	AVERAGE INCIDENTS/YR	DAMAGE $/INCIDENT
DROPPED IN HANDLING	45	2974	133830	21.3	66
EXTERNAL PUNCTURE	32	219682	7029824	14.8	6865
DAMAGE BY OTHER FREIGHT	27	4077	110079	11.8	151
INTERNAL PRESSURE	4	115	460	1.5	29
CORROSION OR RUST	2	5	10	0.8	3
EXTERNAL HEAT	2	99	198	1.0	50
DEFECTIVE FITTINGS, VALVES OR CLOSURES	29	1178	34162	12.5	41
LOOSE FITTINGS, VALVES OR CLOSURES	101	4798	484598	44.3	48
FAILURE OF INNER RECEPTACLES	1	5	5	0.5	5
BOTTOM FAILURE	10	1015	10150	4.5	102
BODY OF SIDE FAILURE	10	884	8840	3.8	88
WELD FAILURE	4	495	1980	2.0	124
CHIME FAILURE	3	120	360	1.5	40
OTHER CONDITIONS	2	0	0	0.8	0
HOSE BURST (DURING LOADING/ UNLOADING OF TANK TRUCKS)	1	500	500	0.5	500
LOADING/UNLOADING SPILL INVOLVING TANK CARS, TRUCKS & TRAILERS)	2	575	1150	0.8	288
IMPROPER BLOCKING/BRACING (CARGO SHIFTED, FELL OVER, ETC.)	10	687	6870	4.0	69
IMPROPER LOADING (UPSIDE DOWN, ON ITS SIDE, HEAVY FREIGHT ON TOP)	9	860	7740	4.0	96
VEHICULAR ACCIDENT OR DERAILMENT	14	199421	2791894	5.5	14244
TANK CAR/TRUCK/TRAILER LOADING/ UNLOADING SPILL (HUMAN ERROR - NO EQUIPMENT FAILURE)	6	6053	36318	3.0	1009
FRICTION (BETWEEN CONTAINERS OR CONTAINERS & VEHICLE)	3	199	597	1.3	66
TOTAL	317	443742	140666214	139.8	1400

Source: U.S. Dept. of Transportation, Office of Hazardous Materials Transportation data reworked

NOTE: See Appendix for annual detail.

In Exhibit 6.3 the "integrated damage" column shows the type of source which generates the greatest hazard as measured by the product of source frequency and damage. The overwhelming conclusion is that road and rail tanker incidents involving external puncture of the storage vessel and loss of the contained product are the greatest hazard followed by incidents which involve leaks through loose or defective valves, closures and fittings.

The smaller Canadian database confirms these findings. Methanol incidents during transportation in Canada averaged only 3/year in the period 1982-86, but they were substantial and comparable in volume of product spilled to gasoline (8-9 tonnes/spill). Rail tanker incidents accounted for one third of the methanol spills in Canadian transportation. This reflects the importance of the U.S. export market and the current mode for shipping chemical grade methanol out of Alberta. The size of the average rail spill was 150 tonnes (185m3). No casualties were reported from Canadian transportation incidents involving methanol in the period 1982-86.

As the volume of M100 and M85 increases, the movement of methanol will resemble that of gasoline with product moved from bulk terminals some 40-80 kilometres by segmented multi-product 33,000 litre capacity road tankers, and the rail movements in Canada will be replaced by pipeline movement of methanol through pipelines now dedicated to petroleum products, crude oil and LPG.

The major source of incidents involving tankers will continue to be due to equipment (valves, fittings, closures) deficiencies at loading/unloading and human error. The other major source of road tanker incidents is expected to arise from vehicles overturning in poor weather and road conditions, tanker accidents which lead to large volume spills, and losses through shearing of fittings in transfer lines. These incidents pose the greatest hazard in terms of the potential for fire and injury, but the fire hazard is expected to be lower than that from

similar gasoline spills from the risk assessment calculations.

Factors which may increase the safety hazard of methanol compared to gasoline in road and rail tanker movements include:

- higher freqency of fuel deliveries compared to gasoline (or crude oil)
- potential for explosion in partly-filled tankers
- fire-fighters' unfamiliarity with the unique properties of M100, including low luminosity of the flame
- start-up problems in the period when petroleum and methanol fuels are both transported.

A higher frequency of problems due to corrosion and attack on elastomeric seals and hose may be encountered until methanol-compatible materials are substituted. These problems will be offset by the higher resistance to tank puncture when steel tanker construction for methanol replaces aluminum gasoline tanks, and the reduced vulnerability of the public, employees and buildings to heat, injury and damage which follow from the low radiant heat in methanol fires and the low toxicity of the combusted fuel.

On balance, the safety of road and rail transportation will be improved by the switch to methanol fuels. It is not certain that M100 or M85 should be the choice. It is concluded that:

- the relative safety of M85 and M100 in the road and rail tanker environment should be investigated
- detailed specifications need to be prepared for fuel methanol tanker performance to guide designs of new and retrofitted single and multi-compartmented road tankers, since the requirements of the fuel market and the composition of the commodity will differ from chemical grade methanol
- increased monitoring and control will be needed to prevent

derailments; automatic detection of hot journal bearings would be an important contribution

- the comparative risk of unit train and mixed cargo train movements needs investigation before major expansion of the rail mode is undertaken.

6.3 Waterborne Movements

The movement of methanol by ocean tanker is currently restricted by demand to 2000-6000 tonne and smaller cargoes shipped in dedicated stainless steel tankers, or converted small-capacity oil tankers, petroleum product and LPG carriers. The switch to methanol will greatly increase the volume of international water movements by ocean tanker and eventually the size of methanol cargoes. In the U.S. barge movement of petroleum to the mid-West market from the Gulf coast may be switched to methanol movements. Barges and small ships as carriers of methanol are frequent in Europe and seven major incidents involving methanol were reported in western Europe in the period 1969-86 involving an explosion on a tanker in the Rhine and a number of fog-related collisions.

The problems to be encountered as methanol fuel use expands are similar to those involved in road and rail tanker movements (increased tonnage and frequency of shipments, use of vessels not yet reworked for methanol compatibility), but with the following also being important:

- methanol will not present a fire problem that is not already encountered in the movement of certain crude oils that are spiked with the very volatile butane (Alaska Slope and many heavier grades of Middle East crude)
- methanol cargoes can be pumped overboard in case of fire with little risk of continued burning or damage to the environment
- the intensity (heat radiation) from methanol fires will assist in the containment of on-board fires when they occur
- most important: the high electrical conductivity of methanol

compared to gasoline and particularly to crude and fuel oil reduces the accumulation of static charges during fuel loading and unloading which is a frequent source of ignition with hydrocarbon fuels.

Experimental work conducted in Sweden on the discharge of waterborne methanol cargoes simulated releases from ocean tankers under different sea, wind and temperature conditions. The experiments showed that the risk of explosion is small since the methanol concentration overboard did not meet the lower explosion limit even under the most unfavourable conditions of high surface temperatures and in the absence of wind.

Although discharges of methanol could lead to short-term alcohol-seawater concentrations above the 21% methanol content flammable level, in practice mixing is rapid and the concentration rapidly falls below the flammability level and, over a 2-10 day period, far below levels where damage to marine organisms might occur. The environmental risk in methanol spills in water was judged to be less severe than that for petroleum products.

In view of the volumes of methanol which may be transported by water, it is suggested that a risk assessment study be conducted on the movement of methanol by barge on inland waterways, including an assessment of the large capacity loading and unloading systems, storage terminals and traffic control systems that will be necessary. The requirements of the design, construction, inspection and operation of methanol carriers should be precisely defined to guide new vessel construction and refitting for methanol.

6.4 Pipelines

Pipelining of methanol has been demonstrated in an LPG line (Cochin system) and in a crude oil pipeline where the methanol was

preceded and followed by a gasoline buffer. The economy of scale and low operating costs will dictate long-range intracontinental pipeline movements of methanol fuel.

Pipeline spills are infrequent but may be large. Spills of gasoline from pipelines in Canada ranged up to 2,300m3 in 1982-7 and slow leaks can lead to large accumulation over time, such as a recent 1,750m3 leak detected in the Los Angeles area.

The problems foreseen with methanol pipelining are:

- small leaks of methanol may not be observable and spills may accumulate before detection
- movements in existing pipelines will require special clean-up procedures, rust inhibitors and perhaps pipeline rework, since methanol will dislodge rust and other debris and attack pipeline dope and rubber seals
- allowance must be made for water contamination in multi-product lines and for the recovery (treatment) of aqueous methanol fractions; special procedures for treating M85 spills may be required.

The high water solubility of methanol and its rapid biodegradation in soil will minimize the environmental damage and fire risk from M100 spills. The damage area surrounding an ignited methanol leak will be smaller than for petroleum pipelines.

The pipelining of methanol is not expected to produce safety requirements that differ substantially from the general requirements for the pipelining of other hazardous materials such as gasoline.

Particular importance is attached to the special training of operators and inspection of facilities before methanol is introduced to the line. Early detection of spills, the isolation of failed sections

of the pipeline and training of employees in the procedures required are also priorities. Remotely-operated valves should be incorporated in the line to facilitate work on lines which pass through highly-populated areas and inclusion of low discharge pressure automatic shut-down control in addition to existing main line controls is required.

Special tests and inspections should be made of existing pipelines and intermediate product storage (breakout) facilities for corrosion and for material which might fail in the presence of methanol.

The pipelining of methanol is to be encouraged as a safe transport mode in view of the low risk attendant upon the transport of even more toxic and flammable materials such as ammonia and LPG. Dedicated methanol pipelines will maximize safety in this mode.

The prediction of the high level of safety through pipelining methanol should be confirmed by a risk assessment study. Long-term component tests and development of an automatic pipeline leak detection system should be undertaken before large volume shipments and new pipeline construction are undertaken in addition to the support given to the development of a visible, odourous methanol fuel which burns with a detectable flame.

7. -STANDARDS, REGULATIONS AND ASSISTANCE PROGRAM

7.1 The Origin and Responsibility for Standards and Regulations

There is a profusion of standards and regulations (codes) in Canada which have been developed to regulate the quality and safety of vehicle fuels, the transportation of dangerous goods, public and occupational health and protection of the environment. The responsibilities are divided among agencies of provincial and municipal governments and the federal government in general on the basis that federal regulations relate to goods which are transported across provincial boundaries and exports (long distance pipelines, for example) and where only national standards are appropriate (new vehicle standards for emissions, vehicle fuel economy targets and international shipping regulations are typical). Provincial agencies frequently adopt national standards and enforce licencing of premises, inspection of facilities at service stations, and in already-purchased vehicles. Provincial agencies are responsible for fuel safety but work with municipal government to guide the by-laws they set on fire safety, the location of service stations and other fuel storage facilities. There is some overlap in responsibilities.

A partial list of the most visible of the responsibilities related to methanol in its role as a Class 1 flammable liquid (fuel safety regulations), a dangerous good (transportation of dangerous goods) or a hazard (spill control to the environment) is given in Exhibit 7.1.

Overall, the regulations that now control gasoline will apply to methanol but modifications will be necessary in some instances such as test methods which assume a vehicle fuel to be insoluble in water. The following deals with areas where substantial changes in regulations have been made or are required.

Exhibit 7.1

Principal Responsibilities Relating To Transportation of Methanol

ACTIVITY	PRINCIPAL ORGANIZATION	RESPONSIBILITY	METHANOL STATUS
FUEL SPECIFICATION	CANADIAN GENERAL STANDARDS BOARD	RECOMMENDS STANDARD FOR ADOPTION BY PROVINCES	DRAFT STANDARD PREPARED
STORAGE & TRANSFER	FUELS SAFETY BRANCH OR EQUIVALENT PROVINCIAL AGENCY	FACILITY LICENCE, INSPECTION, STANDARDS ADMINISTERS GASOLINE HANDLING ACT OR EQUIVALENT ASSISTS MUNICIPALITIES ON SITING, PLANS	GENERAL CLASS 1 STANDARDS NOT SPECIFIC TO METHANOL
RAIL	CANADIAN TRANSPORT COMMISSION	SHIPPING & CONTAINER SPECIFICATIONS	ADOPTED US DOT REGULATIONS
PIPELINE TRANSPORT	NATIONAL ENERGY BOARD & PROVINCIAL AGENCIES	REGULATION & MONITORING OF SAFETY OF PIPELINES WITHIN ITS JURISDICTION; OTHERWISE PROVINCIAL	NOT ESTABLISHED FOR METHANOL
TRUCK PRESSURE RATING	PROVINCIAL BOILER & VESSEL SAFETY ORGANIZATION	SPECIFICATIONS, CERTIFICATION OF VESSELS	NOT SPECIFIC TO METHANOL
DANGEROUS GOODS TRANSPORTATION	TRANSPORT CANADA	SETS FEDERAL REGULATIONS, SUPPLIES INFORMATION & EMERGENCY ASSISTANCE (CANUTEC) ASSISTS PROVINCIAL DANGEROUS GOODS AGENCIES	SPECIALISTS IN DANGEROUS GOODS TRANSPORT & EMERGENCIES PROVINCIALLY DEAL WITH ROUTING
ENVIRONMENTAL PROTECTION	ENVIRONMENT CANADA (ENVIRONMENTAL PROTECTION SERVICE)	NATIONAL MONITORING OF SPILLS PROVIDES ASSISTANCE, LITERATURE, RESEARCH COORDINATES WITH PROVINCIAL AGENCIES	METHANOL INCLUDED IN MONITORING & LITERATURE
FIRE PROTECTION	FIRE MARSHAL (PROVINCIAL)	PROVIDE SPECIFICATIONS FOR USE, STORAGE OF VOLATILE COMPOUNDS	NO SPECIFIC ORIENTATION OR EXPERIENCE WITH METHANOL
SHIPPING	TRANSPORT CANADA (COAST GUARD)	DISCHARGES FROM SHIPS IN CANADIAN WATERS	
ENERGY EMERGENCY	DEPARTMENTS OF ENERGY (PROVINCIAL)	MONITORS & INSPECTS FAILURES & REPAIRS PIPELINES & OTHER ENERGY COMMIDITY TRANSPORT FACILITY	
ENVIRONMENTAL HEALTH	HEALTH & WELFARE CANADA (HEALTH PROTECTION BRANCH), PROVINCIAL AGENCIES	SURVEYS, STANDARDS, MONITORING	
CHEMICAL SPILLS	CANADIAN CHEMICAL PRODUCERS ASSN.	MAINTAINS 10 REGIONAL TEAMS TO ASSIST IN EMERGENCIES IF CALLED BY PARTICIPATING COMPANY (TEAP)	
OCCUPATIONAL HEALTH & SAFETY	CANADIAN CENTRE FOR OCCUPATIONAL HEALTH & SAFETY (GOVT & BUSINESS)	INFORMATION CENTRE	

7.2 Methanol Fuel Specification

The Canadian General Standards Board (CGSB) is responsible for the development of national standards for fuels which, in general, are accepted by provincial government agencies. The situation is similar in the U.S. where states adopt or modify standards established by the American Society for Testing and Materials. A summary of the draft specification for methanol fuel prepared by the CGSB is given in Exhibit 7.2 (in full in Appendix).

The key features of the draft specification from a fuel safety viewpoint are:

- As with gasoline two grades are defined to provide a balance between cold startability in winter and vapour lock in summer. M88 and M83 grades are thus defined.

- Maximum chlorine, acidity and water contents are defined. This will limit corrosion on storage.

- Colour is included as an option for identification purposes.

- The sulphur content at maximum 0.02% is lower than for unleaded gasoline (0.15%).

The comments related to safety in the draft specification are:

- No definition of maximum flame visibility is given: M88 may not burn with an adequately visible flame.

- Colour is included as an option but addition of a water-soluble dye should be mandatory to assist in the location of spills, especially where these contaminate water.

Exhibit 7.2

Specifications for Methanol Fuel and Unleaded Gasoline

DRAFT METHANOL SPECIFICATION

REQUIREMENTS	SUMMER	WINTER
METHANOL CONTENT, % VOL. MIN.	88	83
HYDROCARBON CONTENT, % VOL. MIN.	5.0	8.0
OXYGENATES (OTHER THAN METHANOL), % VOL.	REPORT	
VAPOUR PRESSURE @ 37.8°C, kPA MIN.	40	69
MAX.	79	107
ACIDITY (AS ACETIC ACID), mg/L, MAX.	30	30
TOTAL CHLORINE CONTENT, mg/kg. MAX.	10	10
LEAD CONTENT, mg/L, MAX.	13	13
PHOSPHOROUS CONTENT, mg/L, MAX.	0.3	0.3
MANGANESE CONTENT, mg/L, MAX.	3	3
SULPHUR CONTENT., % MASS, MAX.	0.02	0.02
WATER CONTENT, % MASS, MAX.	0.5	0.5
PARTICULATE CONTAMINANTS, mg/L, MAX.	2.0	2.0

UNLEADED GASOLINE SPECIFICATION

REQUIREMENTS	SUMMER	WINTER
DISTILLATION: 10% EVAPORATED, °C MAX.	57	52
50% EVAPORATED, °C MAX.	118	113
90% EVAPORATED, °C MAX.	185	185
VAPOUR PRESSURE, kPA MIN.	-	62
MAX.	76	97
LEAD CONTENT, mg/L, MAX.	13	13
PHOSPHOROUS CONTENT, mg/L, MAX.	1.3	1.3
MANGANESE CONTENT, mg/L, MAX.	18	18
SULPHUR (LAMP), % MASS, MAX.	0.15	0.15
GUM, EXISTENT, mg/100mg	7	7
OXIDATION STABILITY (INDUCTION PERIOD), MIN. (AT REFINERY MIN.)	240	240
CORROSION (COPPER STRIP-TEST TUBE) 3 H @ 50°C, MAX.	NO. 1	NO. 1

ANTI-KNOCK QUALITY*	TYPE 1 (R+M)/2	PREMIUM (M)
EASTERN CANADA (INCL.ONT.), COASTAL B.C.	90.0	82.0
MAN. AND SASK.	88.0	80.0
ALTA., INTERIOR B.C., YUKON AND N.W.T.	87.0	79.0

* ANTI-KNOCK QUALITY IS THE MOTOR OCTANE NUMBER (M) AND THE ANTI-KNOCK (OCTANE) INDEX DEFINED AS HALF THE SUM OF THE RESEARCH (R) AND MOTOR (M) OCTANE NUMBERS SHALL BE NOT LESS THAN THAT SPECIFIED FOR TYPE 1 AND PREMIUM GRADES

Source: CGSB, CAN2-3.5-M79 for unleaded gasoline; draft for methanol

- An odourant may be necessary to assist in detection of methanol vapour. The sulphur content of the odourant may be added to that permitted in the specification. (The low sulphur content is highly desirable from a vehicle exhaust emission viewpoint).

- The draft specification contains a welcome note: "This material requires fire-fighting procedures which differ from those of gasoline. Users should become familiar with its toxicity and other handling characteristics and adopt recommended safety procedures including fire-fighting equipment and materials."

7.3 Fuel Handling

The Gasoline Handling Act and Gasoline Handling Code detail the regulations which exist in Ontario to control the safe storage and transfer of gasoline, diesel fuel, fuel oil for heating, kerosene, naphtha and dry cleaning solvent. It details:

- licencing requirements for operation of bulk plants, , service stations and transportation of fuels
- equipment and practices for fuel transportation
- specifications, installation procedures, size limits, separation distances and operation of above and below ground fuel storage tanks and for their disposal
- limits on the size of storage at service stations and bulk plants and operating procedures
- fire and other safety precautions which should be followed in the handling of gasoline and associated products and related equipment.

In Ontario the Gasoline Handling Act is administered by the Fuels Safety Branch of the Ministry of Consumer and Commercial Relations, but groups with other titles in other Ministries deal with these matters in other provinces. In British Columbia, for example, the regulations for

storage tanks form part of the Fire Services Act (based upon the National Fire Code of Canada).

The most complete description of the standards necessary for handling transportation fuels is that given in "Flammable and Combustible Liquids Code Handbook" published by the NFPA and based upon NFPA 30 and NFPA 30a - codes which have been adopted in major part by most states in the U.S.

The NFPA codes provide a distinction between Class 1A and 1B flammable liquids and are therefore more applicable to methanol (Class 1B) than the Gasoline Handling Code of Ontario and equivalents which do not distinguish among Class 1 materials.

It will be appropriate to revise the fire regulations in Canada to include consideration of Class 1B liquids and methanol fuels in general. Certain of the operating procedures in the Gasoline Handling Act are inapplicable and revisions will be needed.

The following should be considered as part of a methanol fuel code or for future revisions of the existing codes:

- The maximum size of the fuel inventory at stations might be increased somewhat in view of the reduced area exposed in M100 fires compared to gasoline fires.

- Tank and other separation distances might be reduced for the same reasons.

- Specifications for the storage tanks should provide methanol compatibility. Double-walled underground tanks might be specified as in California.

- Materials or other components (hoses, tanks, pipes, valves, seals)

should be defined as methanol-resistant.

- The requirements for flame arrestors or equivalent would be defined.

- New procedures for measuring the level of methanol will be required in view of the water solubility of the fuel.

- Fire extinguisher types should be defined to include methanol-compatible types and notice given of the inapplicability of foams that are not alcohol-resistant.

- More attention should be given to avoidance of contact and inhalation of vapours because of the lower recommended levels of exposure for methanol compared to gasoline.

- Signage at service stations might be revised to emphasize the toxicity of methanol and gasoline.

New dispenser regulations are being introduced in British Columbia to improve safety at self-service stations. These will be applicable to methanol where consideration should also be given to the inclusion of vapour recovery systems at dispensers.

Co-operation between provincial fuel safety groups, fire department and municipal planning authorities will be required to effect these changes and to provide new training and training aids to emergency response and fire department personnel.

7.4 Dangerous Goods and Hazardous Substances Regulations and Assistance

Substantial monitoring and reporting requirements have been established throughout Canada to provide better information and services

in the event of spills of dangerous cargoes and hazardous substances, methanol being included in both categories.

Transport Canada's Dangerous Goods Transportation Directorate has established the regulations at the federal level. Provincial agencies and even municipal agencies are also involved in regulating dangerous goods transportation and excellent co-operation exists (see Appendix for the provincial and federal contact list on Dangerous Goods). For example, the cities of Calgary and Edmonton have instituted dangerous goods regulations which prescribe the routing and time of delivery for gasoline and other dangerous goods transporters in their communities.

Environment Canada has taken a similar position in the monitoring, reporting of spills which have environmental implications and in effecting liaison with provincial environmental protection agencies.

A point of note is that both the dangerous goods and environmental groups have taken an active position through the establishment of emergency response centres such as CANUTEC (Canadian Transport Emergency Centre) which provides information and personnel when notified of emergencies .

The Canadian Chemical Producers' Association, in close co-operation with CANUTEC, maintains the Transportation Emergency Assistance Program (TEAP) which provides technical information to emergency forces at sites of transportation mishaps involving chemicals; specialist teams are sent when needed.

The regulations under the federal Dangerous Goods Act require every owner-shipper of items on the dangerous goods list to have an approved emergency response plan.

The heightened awareness of the fire and health implications of spilled materials among producers, shippers and distributors of

chemicals, among government agencies, industry associations and the public have laid the foundation for the safe introduction of methanol fuels.

The adoption of methanol as a transport fuel would so alter the volumes needed that methanol would become the highest volume synthetic chemical product. The processes already developed to monitor and control the safe storage, distribution and use of the product provide an encouraging basis for that expansion.

8. CONCLUSIONS

8.1 Methanol Fuel Safety

The switch to high methanol-content fuels will increase the volume of hazardous fuels stored and transported compared to the existing system based on long-distance transportation of crude oil and more local movements of gasoline and diesel fuel from the refinery to the end-user.

The wide flammability range of methanol will increase the frequency of fires in the transportation fuel system, particularly in the period when methanol and conventional hydrocarbon fuels co-exist in the storage and distribution networks.

The low visibility of M100 will increase the difficulty of detection of fuel fires, a difficulty which may be overcome by use of methanol fuels containing gasoline, such as M85. The low odour of M100 increases the likelihood that small leaks may not be detected early and the absence of colour and water solubility of M100 make detection of liquid spills more difficult than is the case with gasoline or diesel fuel. This lack of odour can be resolved by use of M85, or formulations which contain odourants such as those now added to natural gas and propane. Use of M85 or the addition of a dye will improve the visibility of liquid methanol fuel spills.

The toxicity of methanol by inhalation or skin contact is somewhat higher than that of gasoline and diesel fuel. More precautions will be required in handling methanol than conventional hydrocarbon fuels. Ingestion of methanol, whether accidental or deliberate, presents a significant but low frequency fatality and toxicity risk, substantially higher than the comparable risk from gasoline ingestion. The carcinogenicity, however, of benzene, which may be a major component of gasoline, may present a longer-term industrial health problem than methanol.

- These disadvantages of methanol are offset by the low radiant heat and absence of smoke in methanol fires. The fire damage and injury area in methanol fires is calculated to be substantially smaller than that from similar volume fires of gasoline or diesel fuel. The advantage is only slightly reduced when M85 is used. The overall assessment of the safety of methanol is as follows:

Spill Area	Hazard Comparison
Ocean tanker, barge	Similar to gasoline, crude oil, higher than diesel fuel
Rail and road tanker	Similar to gasoline
Pipeline	Lower than gasoline
Bulk storage and service station	Reduced fire hazard compared to gasoline increased compared to diesel fuel, health hazard similar to gasoline
Repair shop, garage	Small increase in fire hazard compared to gasoline

8.2 New Information Required

More information is needed on:

- the importance of low methanol flame visibility in fires
- experimental data on the ignition of methanol vapours in enclosed spaces, comparison with gasoline
- formulations which provide luminous flames without the disadvantages associated with addition of aromatic gasolines.

9. RECOMMENDATIONS

1. Development of the methanol fuel market should not be delayed by concerns over the relative safety of these fuels compared to gasoline.

2. Regulations relating to the safety of transport fuels should be revised to include safety factors needed in the storage, transportation and distribution of high methanol-content fuels.

3. An investigation should be undertaken to provide information on the consequences to public and fuel industry health from use of methanol fuels compared to use of gasoline and diesel fuel. The investigation should include consideration of the exposure of the public and industry employees to these fuels and to the products of their combustion in vehicles.

4. Technical investigations should be made to provide:

- means to detect methanol fires
- an understanding of the relative hazard of methanol and gasoline fires in enclosed spaces such as tanks and garages
- formulations of methanol fuel that will provide colour, odour and improved flame visibility, and which will minimize the frequency of fuel ingestion.

GLOSSARY

GENERAL

Fuel Transfer: Transfer of gasoline, diesel or methanol between a vehicle and a fuel storage tank. Examples are vehicle refuelling from a road tanker to the storage tank at a service station.

Service Station (Public): Location where vehicle fuels are dispensed to the general public.

Service Station (Private): Privately-owned facilities where company-owned and other fleets of vehicles are refuelled. These facilities are not open to the public.

PHYSICAL PROPERTIES OF FUEL

Boiling Point: The temperature at which the liquid boils. Methanol has a definite boiling point, while gasoline and diesel fuel, being mixtures, boil over a range of temperatures.

Explosion: A sudden and violent expansion caused by the rapid burning of gasoline, diesel fuel or methanol. The rapid expansion is accompanied by a noise, a shock wave and the liberation of large amounts of heat.

Liquid Density: The density of the liquid compared to water, which has a density of 1gram/mL.

Vapour Density: The density of the vapour compared to air.

Reid Vapour Pressure: The pressure exerted by the vapour over the liquid in a closed container of a specified type. Reid vapour pressure is a measure of the fuel volatility.

Heat of Vapourization: The amount of heat energy required to convert liquid to vapour.

COMBUSTION PROPERTIES OF FUEL

Ambient (temperature, pressure): Surrounding the facility, prevailing.

Flash Point: The temperature at which a liquid produces sufficient vapour for immediate ignition by an external ignition source. If a flammable substance is not above its flash point, it must be heated to the flashpoint before ignition can occur.

Auto-Ignition Temperature: The temperature at which a substance will ignite in air in the absence of an external ignition source. Ignition from heat alone and not from a spark or flame.

Minimum Energy for Ignition: The minimum spark size required to ignite the most flammable mixture of the vapour and air under the most favourable conditions.

Flammability Limits: The fuel concentration range (in volume % of fuel vapour in air) over which burning can occur. Below the lower flammability limit there is insufficient fuel to burn. Above the higher flammability limit there is insufficient air to support combustion.

Luminosity: Giving off light. In fuels luminosity is associated with the light emitted from soot and combustible particles in the flame.

Flame Visibility: The amount of visible light produced by a flame relative to unleaded gasoline.

Flame Spread Rate: The speed with which a flame will spread across the surface of a liquid pool of fuel.

Peak Flame Temperature: The maximum temperature of a flame burning a stoichiometric mixture (neither fuel nor air is in excess) of fuel and air.

HEALTH AND SAFETY PROPERTIES OF FUEL

Incident: An event which causes or has the potential to cause an escape of fuel which may or may not ignite.

Odour Threshold: The lowest concentration at which an odour can be detected by smell compared to purified, odour-free air.

TLV: Threshold limit value. The airborne concentration of a substance to which workers may be exposed daily without adverse effect.

Leak: An escape of gasoline, diesel or methanol from a container, tank or vessel through a crack, hole or faulty closure.

STEL: Short-term exposure limit. A threshold limit value. The maximum concentration to which workers can be exposed for a period of up to 15 minutes without suffering from irritation, tissue change, or narcosis.

Risk: The chance of encountering harm or loss. Hazard, danger.

Radiant Heat: The heat energy radiated from a fire. Differs from convective heat due to movement of hot air and combustion products and conductive heat that is transmitted along metal and other materials.

Toxicity: The degree of intensity of a poison.

APPENDIX

1. DRAFT SPECIFICATION OF CANADIAN COMMERCIAL FUEL METHANOL (CANADIAN GENERAL STANDARDS BOARD)

2. RISKS OF METHANOL FUELLING STATIONS (J.M. BRUGGEMAN, TNO)

3. CAUSE PROFILES FOR U.S. PUBLIC SERVICE STATION STRUCTURE FIRES INVOLVING GASOLINE AS MATERIAL FIRST IGNITED

4. PRIMARY FAILURE ANALYSIS - U.S. METHANOL INCIDENTS IN TRANSPORTATION

5. RECOMMENDED COMPONENTS AND MATERIALS FOR METHANOL REFUELLING STATIONS IN CALIFORNIA

6. DANGEROUS GOODS CONTACT LIST

7. REFERENCES

APPENDIX 1
DRAFT SPECIFICATION OF CANADIAN COMMERCIAL FUEL METHANOL (CANADIAN GENERAL STANDARDS BOARD)

1.0 SCOPE

This standard applies to two grades of automotive fuel in which the major component is methanol. Light hydrocarbon components such as butane, iso pentane, light naphtha and unleaded gasoline are included in these blends in order to promote safety in storage tanks, impart flame luminosity and to provide the required volatility for satisfactory year round operation in the spark ignition engines of vehicles designed to use methanol fuel. Oxygenated componds such as dimethylether and methylal may be incorporated to further improve the volatility.

2.0 APPLICATION PUBLICATIONS

2.1 The following publication(s) are applicable to this document.

2.1.1 American Society for Testing Materials (ASTM)

Annual Standards - Volumes 03.05, 05.01, 05.02, 05.03, 08.03, 15.05

E-29 - Recommended Practice for indicating which place of figures are to be considered significant in specified limiting values.

2.2 Reference to the above publications is to the latest issues. The source of these publications will be found in Section 7 - "Notes".

3.0 CLASSIFICATION GRADES

3.1 The methanol fuel shall be supplied in two grades:

3.1.1 Grades:

Summer - (Supplied 1 May to 30 September inclusive)
Winter - (Supplied 1 October to 30 April inclusive)

4.0 GENERAL REQUIREMENTS

4.1 The fuel shall consist of a single clear phase, free of suspended matter, and shall remain homogenous at minimum anticipated temperatures.

4.2 Colour: May include a dye in accordance with standard practicce for purpose of product identification.

4.3 Other appropriate additives, e.g. corrosion inhibitors, detergents, and upper cylinder lubricants may also be included in the formulation.

4.4 No lead or phosphorus shall be added.

5.0 DETAIL REQUIREMENTS

The fuel shall comply with the requirements listed below, the limits of which are absolute and not subject to correction for tolerance of test methods.

	REQUIREMENTS	SUMMER	WINTER	TEST METHODS & NOTES
5.1	Methanol Content, % Vol.Min.	88	83	(a)
5.1.1	Hydrocarbon Content, % Vol.Min.	5.0	8.0	(a), (d)
5.1.2	Oxygenates (other than methanol),% Vol.	REPORT		(a)
5.2	Vapour Pressure @ 37.8°C			
	- kPa Min.	40	69	ASTM D 323 (b)
	- kPa Max.	79	107	ASTM D 323 (b)
5.3	Acidity (as acetic acid) mg/L, Max.	30	30	ASTM D 1613
5.4	Total Chlorine Content, mg/kg, Max.	10	10	(c)
5.5	Lead Content, mg/L, Max.	13	13	ASTM D 3237
5.5.1	Phosphorus Content, mg/L, Max.	.3	.3	ASTM D 3231
5.5.2	Manganese Content, mg/L, Max.	3	3	ASTM D 3831
5.5.3	Sulphur Content, % mass, Max.	0.02	0.02	ASTM D 3120
5.5.4	Water Content, % mass, Max.	0.5	0.5	ASTM E 203
5.5.5	Particulate Contaminants, mg/L,Max.	2.0	2.0	ASTM D 2276

(a) Several chromatographic methods are suitable to determine methanol, light hydrocarbon and other oxygenate content.

(b) Dry method.

(c) No generally accepted test procedure at this time - several methods available.

(d) Dependent upon the volatility and concentration of the hydrocarbon components and ambient temperature, the blended methanol fuel may, or may not, produce the desirable non-flammable vapour condition in fuel tanks.

6.0 INSPECTION

6.1 Sampling - A 4L sample of the finished fuel shall be obtained in accordance with procedures defined in ASTM D 4057.

7.0 NOTES

7.1 Precautions - This material requires fire-fighting procedures which differ from those of gasoline. Users should become familiar with its toxicity and other handling characteristics and adopt recommended safety procedures including appropriate fire-fighting equipment and materials.

7.2 Options - The grade option provided in this document should be specified in its application.

7.3 The publications listed in par. 2.1.1 may be obtained from The American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA., 19103, U.S.A.

APPENDIX 2

Netherlands
organization for
applied scientific
research

TNO-report

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Title
RISKS OF METHANOL FILLING STATIONS

Draft report

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Keyword(s):
- risk assessment
- filling station
- comparison methanol - gasoline

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SUMMARY

In this report the risks of a methanol filling station are compared with a gasoline filling station, which risks are analysed in the TNO gasoline risk assessment study [1].

It is assumed that both filling stations will be the same. So the same undesirable events with escaping quantities are to be expected. In this global risk comparison also no differences in probabilities of occurrence were found.

So differences only arise from differences in the possible effects. In this case poolfire effects determine the individual risk curve for a filling station.

From effect calculations and from a comparison of individual risk curves it follows that up to a distance of 20 meter: the risks are the same for a methanol and a gasoline filling station. Above 20 meter the individual risk of methanol is less due to a lower radiation intensity of a poolfire.

1. INTRODUCTION

At the request of R.W. Webb Corporation Ltd. the department of Industrial Safety of TNO (The Netherlands) has reviewed the risks of a methanol filling station (storage, handling and loading/unloading of methanol) by comparison with a gasoline filling station from the extensive TNO gasoline risk assessment study [1].

The comparison is carried out with the assumptions that the standard throughput, number of transshipments, quantities and other system characteristics of a menthanol filling station in the TNO study [1]. So possible differences may arise only from a difference in the hazardous properties of methanol compared to gasoline.

A short description of the risk assessment study of the gasoline filling station is presented first. Thereafter a comparison of the combustion parameters and other physical properties of methanol with gasoline is made.

2. GASOLINE RISK ASSESSMENT STUDY

This chapter gives a short description of the starting-points and the results of the risk assessment study of the gasoline filling station [1].

2.1 Description of the gasoline filling station

At filling stations the gasoline is stored in underground tanks with capacities of 12 to 50 m^3.
The gasoline is transshipped from a tank truck to the underground storage tank and from this storage tank through the petrol pump to the car's petrol tank.
Tank trucks are articulated vehicles. The largest tank trucks have a loading capacity of 48 m^3. The tanks on a truck are divided into compartments, the number depending on the total capacity. The tank truck driver carries out the onloading.
The rate of transfer is about 110 m^3/hr.
The filling of the petrol tanks of cars takes place with pumps at a rate of about 2,5 m^3/hr. When the tank is almost full, the filling stops automatically.
In the study [1] the following standard quantities for the filling station are used:

	standard throughput (tonnes p.a.)	number of transshipments (p.a.)	time taken by one transshipment (mintutes)
Transshipment from a tank truck	500	15	30
Filling petrol tanks of cars	500	17,000	1

2.2 Results of the risk assessment

A risk assessment contains a determination of undesirable events, the probability of these events occurring, the calculation of the possible effects of these events and the graphical presentation of these risks. The probabilities are derived from incident data of casuistry or by means of fault trees.

The effect and damage distances resulting from an escape of gasoline are calculated with models of TNO presented in [1].

Delayed ignition does not apply in any of the cases considered. The results are given below in table 2.1. and in figure 1. Figure 1 is an individual risk curve, which is defined as the probability of an individual suffering fatal injuries at several distances from the installation.

Table 2.1: Outline of the risk at a gasoline filling station

Undesirable event	Probability of occurrence per year *)	Escaping quantity	Damage distances(m) Immediate ignition	
			Radius of pool 100% fatalities	Heatradiation 1% fatalities
* Stationary situation (storage) No undesirable events				
* Transshipment from tank truck				
1. Truck failure (internal failure, mechanical impact)	0.13×10^{-7}	21 kg/s	9	40
2. Truck failure (fire)				
aluminium	0.18×10^{-7}	35,000 kg	20	80
sheet steel	0.18×10^{-12}	7,400 kg	25 **)	80
3. Escape from tank truck	0.12×10^{-2}	23 kg/s	10	40
* Transshipment to car				
4. Escape from hose	0.05	1 kg/s	1	5

*) Quantity transferred p.a. of 500 tonnes.
**) Radius of fire-ball.

3. PROPERTIES OF METHANOL VERSUS GASOLINE

Given the assumption that the system characteristics of a methanol filling station will be the same as for the gasoline filling station, the undesirable events will also be the same. Differences in risks will then only be caused by differences in fire and other physical properties of the materials. In this chapter the important properties are outlined.

An extra hazard of methanol with respect to gasoline is its toxicity. Methanol has a STEL (Short Term Exposure Limit) of 250 ppm (= 330 mg/m3) and an LC50 for rats of 64,000 ppm (= 85,300 mg/m^3) for an exposure time of 4 hours. An LC50 is the concentration at which 50% of the test species dies [2]. The relevance of the toxicity for the individual risk curve is considered in par. 4.1.

Some properties of methanol and gasoline are listed in table 3.1. The properties are taken from [1], [3] and [4].

Table 3.1: Properties of methanol and gasoline

	Methanol	Gasoline
Molecular weight [kg/kmol]	32	98
Density of liquid, 15°C [kg/m^3]	800	735
Boiling point [K]	337.7	333 - 472
Flash point [°C]	10	-40
Ignition temperature [K]	737	729
Minimum ignition energy [mJ]	0.14	0.28
Explosive limits [% volume]	6.0 - 36.5	1.4 - 7.4
Vapour pressure, 20% [bar]	0.127	0.4
Heat of vaporization [J/kg]	$11.0 \cdot 10^5$	$3.0 - 3.4 \cdot 10^5$
Heat of combustion [J/kg]	$195.8 \cdot 10^5$	$435.1 \cdot 10^5$
Liquid heat capacity [J/kgK]	2,408	2,194

The main conclusions from a comparison of the relevant properties with regard to the risks are:

- methanol is less volatile; the evaporation rate is lower (lower vapour pressure; higher heat of vaporization),
- both are highly inflammable (flash point below 21°C),

- a methanol vapour cloud in optimal ratio will already ignite at lower energy sources (lower minimum ignition energy),
- the lower explosion limit of methanol is higher,
- a methanol fire has a lower maximum intensity of radiation (lower heat of combustion).

The consequences of these differences in properties of methanol and gasoline on the effect and damage calculations are discussed in the next chapter.

4. RISKS OF METHANOL VERSUS GASOLINE

4.1 Comparison of the effects

For the risk comparison the same undesirable events are assumed for a methanol filling station as for the gasoline filling station (see chapter 2.).
It is expected that the escaping quantity and the pool formation will be the same for both systems.
With the given pool sizes, it is calculated that both for gasoline and for methanol a flammable vapour cloud can only be present above the poolsurface. That means that only the pool fire heatradiation effects determine the differences in the individual risk curve.
In [1] the following damage criteria for a poolfire were used. Anyone within the dimensions of the burning pool will be burnt to death or suffocate (100% fatality rate). In the area outside the pool up to the distance where the heat radiaton is 7.5 kw/m², 1% fatality is assumed.
As can be seen from the comparison of properties in chapter 3, the radiation effects for methanol will be less than for gasoline. These effects are calculated with the TNO-program EFFECTS.
The results are presented in table 4.1.

Table 4.1: damage distances for methanol and gasoline poolfires.

Damage distances (m) for pool fires		
Radius of pool (100% fatalities)	Heat radiation (1% fatalities)	
	Methanol	Gasoline
r = 20 m	25	80
r = 10 m	13	40
r = 1 m	1.5	5

Toxicity aspects

Evaporation and dispersion calculations for methanol were carried out with EFFECTS to see what the effects will be of the

formation of a toxic cloud. Rough calculations show that no letalities are to be expected in the surroundings of a methanol filling station. For a poolradius of 10 or 20 m. the concentration of the toxic cloud exceeds the STEL-value of methanol up to several hundreds of meters.

4.2 Comparison of the probability of occurence

For the individual risk curve of the gasoline filling station only scenarios 3 and 4 from table 2.1 are relevant with respect to probability of occurrence. The scenarios are the escape from a tank truck during transshipment from the tank truck respectively the escape from the hose during transshipment to a petrol tank of a car.
For these two scenarios fault trees were made in [1] to see what factors or events contribute to an escape.
Both fault trees are dominated bij failures of human actions. It is not likely that human failures or the probabilities of occurrence will be different for a methanol or a gasoline filling station. Also because these probabilities are just general.

Another probability aspect is the probability of ignition. In [1] a probability of 0.065 is assumed for direct ignition, which leads to a pool fire. This value is based on casuistry of gasoline escapes and fires.

Methanol has a lower mimimum ignition energy. But without further study it can not be concluded whether there will be differences in igniting gasoline or methanol by sources present on a filling station, like e.g. running motors, mechanical sparks or fires.
In this study the probabilities of ignition for gasoline and for methanol are assumed to be the same.

4.3 Comparison of individual risks

With the calculated damage distances for methanol poolfires in table 4.1 and the arguments of 4.2 that there is no difference in the probabilities, an individual risk curve for a methanal filling station can be

drawn.
The from this global study resulting individual risk curve is drawn in figure 1.
In figure 1 also the individual risk curve for gasoline from [1] is drawn. From a comparison it follows that up to a distance of 20 meter the individual risk is the same for both. Above 20 meter the individual risk of methanol is less due to a lower radiation intensity of a pool-fire.

5. EVALUATION

This study is carried out on the basis of the assumptions that the system characteristics, and therefore the undesirable events and quantities, the probability of human failure and the ignition probability on a methanol filling station will be the same as for the gasoline filling station in the TNO study [1].

The poolfire scenarios are relevant for the individual risk curve.

Therefore differences in the individual risk for methanol and gasoline arise from differences in radiation intensity from poolfires. Methanol has a lower heat of combustion and therefore a lower intensity of radiation, which results in a lower individual risk.

With use of more specific data on a methanol filling station and review of methanol incidents casuistry, a more detailed risk assessment study can be carried out. The toxicity of methanol can be further considered.

On the same basis it is also possible to compare other methanol activities like transport or depots with the gasoline activities analysed in [1].

6. LITERATURE

[1] LPG, a study.
A comparative analysis of the risks inherent in the storage, transshipment, transport and use of LPG and motor spirit.
TNO report (1983).
Part 2123: storage and transshipment of motor spirit at the filling station (in dutch).

[2] RTECS.
Registry of Toxic Effects of Chemical Substances.
NIOSH, 1981-82.

[3] CHRIS.
Hazardous Chemical Data.
Department of Transportation, Coast Guard, 1974.

[4] Handling Chemicals Safety.
Dutch Association of Safety Experts, Dutch Chemical Industry Association and Dutch Safety Institute, 1980.

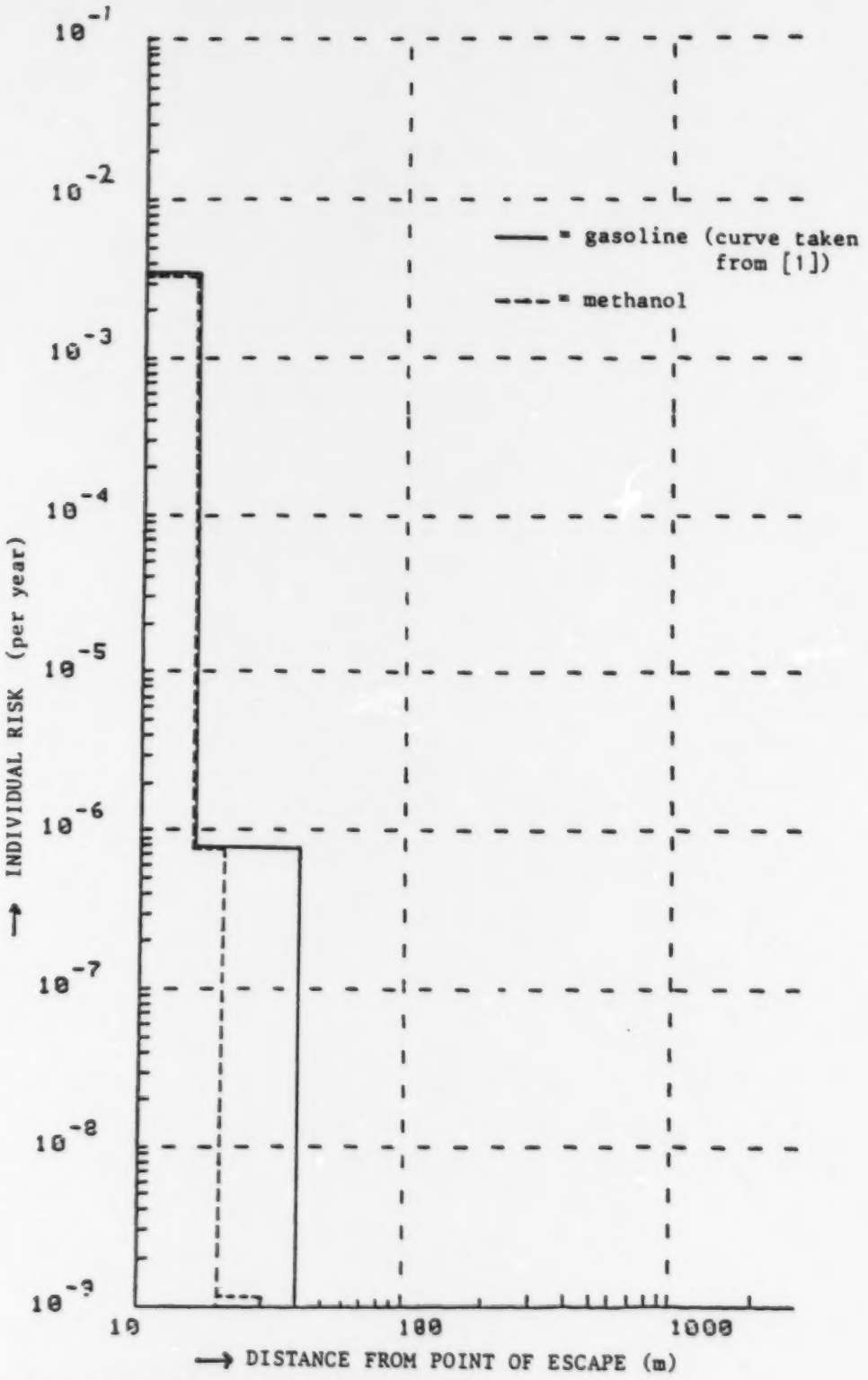


Figure 1: Individual risk curve relating to the storage and transhipment at a filling station.
Throughput: 500 tonnes p.a.

17755/8727-15021/PTN/BAK d.d. 25 August 1988

COMPARISON OF THE RISKS OF METHANOL AND M85 VERSUS GASOLINE

In the report (no. 88-071/C1) of February 1988 the comparison of the risks from a methanol fuel filling station with a gasoline fuel filling station has been presented.
The risk of a gasoline fuel filling staion is extensively analysed in LPG, a study (1983, TNO).
The same procedure is also used for the comparison for the fuel M85, a mixture of gasoline (15%) with methanol (85%).
This means that the same release scenarios are used for the risk analyses, and while no other figures are present also the same probabilities are used.
The risk of a fuel filling station is determined by possible poolfires, so the poolfires effects of the different fuel are compared.

Tabel 1 Properties of gasoline, methanol (M100) and M85.

	Gasoline	Methanol	M85 *
Molecular weight [kg/kmol]	98	32	42 **
Liquid density, 15°C [kg/m^3]	735	800	745 **
Boiling temperature [k]	333-472	337.7	333-472 **
Flash point [°C]	-40	10	-40 ***
Ignition temperature [k]	729	737	737 **
Minimum ignition energy [mJ]	0.28	0.14	0.14
Explosive limits [% volume]	1.4-7.4	6.0-36.5	2-34
Vapor pressure, 20°C [bar]	0.4	0.127	0.28 **
Heat of vaporization [I/kg]	$3.0\text{-}3.4.10^5$	$11.0.10^5$	$9.8\text{-}10^5$ **
Heat of combustion [I/kg]	$435.1.10^5$	$195.8.10^5$	$231.7.10^5$ **
Liquid heat capacity [I/kg k]	2.194	2.408	2.376 **

* Estimated based on methanol fuel safety, technical report, October 1987
** Estimated based on combination gasoline and methanol
*** Estimated based on equivalency with methanol

Use is made of the properties mentioned in table 1 to compare the poolfire effects for the different fuels.
The poolfire effects are calculated with the TNO-program EFFECTS. The results are presented in table 2.

Table 2 Damage distances for different fuel poolfires

Damage distances (m) for poolfires			
Radius of pool (100% fatalities	Heat radiation (1% fatalities)		
	gasoline	Methanol	M85
20	80	25	29
10	40	13	15
1	5	1.5	1.7

The heat radiation effects are determined by the following physical properties of the burning material: heat of combustion, heat of vaporization and liquid heat capacity.
For M85 these properties were estimated based on the combination of methanol and gasoline. Therefor these properties of M85 are almost the same as for methanol, so also their damage distances will be about the same (see table 2).

The calculated damage distances from table 2 and the probabilities established in LPG. a study, are used to draw the individual risk curves presented in figure 1.
The individual risk curve for methanol and for M85 are the same, because their damage categories are the same.

APPENDIX 3

CAUSE PROFILES FOR U.S. PUBLIC SERVICE STATION STRUCTURE FIRES INVOLVING GASOLINE AS MATERIAL FIRST IGNITED

MAJOR CAUSE	% OF FIRES
Other equipment	34.1
Electrical distribution	18.0
Match, lighter, other open flame	10.7
Heating equipment	9.8
Incendiary or suspicious	9.7
Other heat source	5.0
Smoking materials	2.5
Appliances, tools, air conditioning	2.3
Natural causes	2.1
Exposure	1.5
Cooking equipment	0.2
Unknown causes	4.1
Average annual fires	387

Source: U.S. National Fire Protection Association, 1987

APPENDIX 4

Primary Failure Analysis - U.S. Methanol Incidents in Transportation

	1984		1985		1986		1987		TOTAL	
	#	DAMAGE $	#	DAMAGE $	#	DAMAGE $	#	DAMAGE $	#	DAMAGE $
DROPPED IN HANDLING	5	160	4	1094	9	552	27	1168	45	2974
EXTERNAL PUNCTURE	5	6892	4	315	16	208985	7	3490	32	219682
DAMAGE BY OTHER FREIGHT	7	1519	3	170	9	873	8	1515	27	4077
INTERNAL PRESSURE	2	55	2	60	-	-	-	-	4	115
CORROSION OR RUST	1	0	1	5	-	-	-	-	2	5
EXTERNAL HEAT	-	-	-	-	-	-	2	99	2	99
DEFECTIVE FITTINGS, VALVES OR CLOSURES	8	149	6	150	10	780	5	99	29	1178
LOOSE FITTINGS, VALVES OR CLOSURES	25	430	25	1000	26	2836	25	532	101	4798
FAILURE OF INNER RECEPTACLES	-	-	-	-	-	-	1	5	1	5
BOTTOM FAILURE	2	250	3	235	-	-	5	530	10	1015
BODY OF SIDE FAILURE	5	480	1	100	4	304	-	-	10	884
WELD FAILURE	-	-	1	125	1	250	2	120	4	495
CHIME FAILURE	-	-	1	0	1	0	1	120	3	120
OTHER CONDITIONS	1	0	1	0	-	-	-	-	2	0
HOSE BURST (DURING LOADING/ UNLOADING OF TANK TRUCKS)	-	-	1	500	-	-	-	-	1	500
LOADING/UNLOADING SPILL INVOLVING TANK CARS, TRUCKS & TRAILERS)	1	75	-	-	-	-	1	500	2	575
IMPROPER BLOCKING/BRACING (CARGO SHIFTED, FELL OVER, ETC.)	4	197	4	490	-	-	2	0	10	687
IMPROPER LOADING (UPSIDE DOWN, ON ITS SIDE, HEAVY FREIGHT ON TOP)	2	280	3	165	1	100	3	315	9	860
VEHICULAR ACCIDENT OR DERAILMENT	6	161128	4	8743	-	-	4	29550	14	199421
TANK CAR/TRUCK/TRAILER LOADING/ UNLOADING SPILL (HUMAN ERROR - NO EQUIPMENT FAILURE)	-	-	2	435	4	5618	-	-	6	6053
FRICTION (BETWEEN CONTAINERS OR CONTAINERS & VEHICLE)	1	100	-	-	-	-	2	99	3	199
TOTAL	75	171715	66	13587	81	220298	95	38142	317	443742

Source: U.S. Dept. of Transportation, Office of Hazardous Materials Transportation, 1988

APPENDIX 5

Recommended Components and Materials for Methanol Refueling Stations in California

Component	Recommended Material or Product
Underground storage tank	New, unused carbon steel or stainless steel
Piping	New, unused carbon steel, cast iron, or black iron
Pipe fittings	New, unused carbon steel, cast iron, black iron, marine brass, or stainless steel
Pipe thread sealant	Teflon®
Fuel pump	Tokheim model 785 PR or Redjacket model CP33R1 modified for methanol
Fuel dispenser	Tokheim 1200 series or 1250 series modified for methanol
Flow regulator	Emco Wheaton model A10 (currently made from aluminum, to be replaced with new cadmium-plated steel device when available)
Dispenser filter	AMF Cuno model 1B2 filter housing and AMF Cuno model D-CCSB-2 Micro Wynd II filter cartridge
Dispenser hose	Goodall model N-2494 cross-link polyethylene hose with electrically grounded brass couplings
Hose swivel	Brass, stainless steel, or anodized aluminum (Husky Corporation model 1+VI)
Dispensing nozzle	Emco Wheaton model A3003

Source: Private communication Argonne National Laboratory

APPENDIX 6

Transport Canada | Transports Canada

Dangerous Goods | Marchandises dangereuses

Canada

Dangerous Goods

Contact List

Part I — Federal Regulatory Agencies

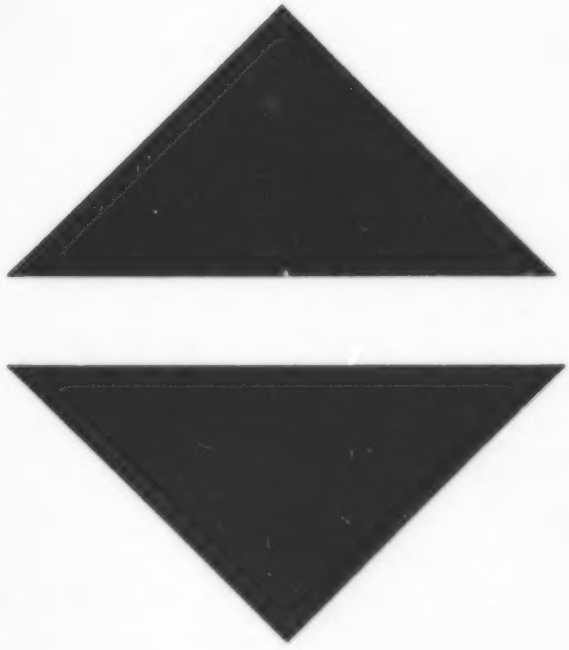
Part II — Provincial Regulatory Agencies

Marchandises dangereuses

Liste des personnes — ressources

Partie I — Organismes fédéraux de réglementation

Partie II — Organismes provinciaux de réglementation



MARCH 1987 | MARS 1987

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Part I — Federal Regulatory Agencies

Partie I — Organismes fédéraux de réglementation

Consignors, Manufacturers, Consignees, Warehousemen, Freight Forwarders, Brokers, etc.

Transport Dangerous Goods
Transport Canada
Place de Ville
OTTAWA, Ontario
K1A 0N5
Telephone: (613) 992-4624
Telex: 053-3130

Regional Manager
Transport Dangerous Goods
Transport Canada
Suite 315
549 Columbia Street
New Westminster, **BRITISH COLUMBIA**
V3L 1B3
Telephone: (604) 666-2955

Regional Manager
Transport Dangerous Goods
Transport Canada
101-22nd Street East
Room 604, Federal Building
Saskatoon, **SASKATCHEWAN**
S7K 0E5
Telephone: (306) 975-5105

Regional Manager
Transport Dangerous Goods
Transport Canada
391 York Avenue
Room 305
Winnipeg, **MANITOBA**
R3C 0P4
Telephone: (204) 949-5969

Expéditeurs, fabricants destinataires, magasiniers, transporteurs, courtiers, etc.

Regional Manager
Transport Dangerous Goods
Transport Canada
Canada Centre
200 Town Centre Court, 8th Floor
Scarborough, **ONTARIO**
M1P 4X8
Telephone: (416) 973-4599

Gestionnaire régional
Transport des marchandises dangereuses
Transports Canada
Édifice du Port de Montréal
Cité du Havre, Aile 3
3e étage
Montréal **(QUÉBEC)**
H3C 3R5
Téléphone: (514) 283-7369

Regional Manager
Transport Dangerous Goods
Transport Canada
5670 Spring Garden Road
7th Floor
Halifax, **NOVA SCOTIA**
B3J 1H6
Telephone: (902) 426-6532

Air Transport — Transport aérien

Manager, Dangerous Goods
Aviation Regulation Branch
Operations and Certification Division
Aviation Group
Transport Canada
Centennial Towers, 5th Floor
200 Kent Street
OTTAWA, Ontario
K1A 0N8
Telephone: (613) 990-1059
Telex: 053-3130

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Aviation Regulation Branch
Air Carrier Inspection Division
Transport Canada
800 Burrard Street
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Vancouver, **BRITISH COLUMBIA**
V6Z 2G7
Telephone: (604) 666-5655
Telex: 04-54320

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Aviation Regulation Branch
Air Carrier Inspection Division
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Edmonton, **ALBERTA**
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Telex: 037-2469

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Air Carrier Inspection Division
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Moncton, **NEW BRUNSWICK**
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Telex: 014-2666

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Telex: 06-986553

Marine Transport – Transport maritime

Senior Surveyor Dangerous Goods
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Région des Laurentides
Garde côtière canadienne
104, rue Dalhousie
Sécurité des navires
Québec Terminus
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Regional Surveyor Dangerous Goods
Maritimes Region
Canadian Coast Guard
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Alderney Drive, 11th Floor
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Telex: 019-22510

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Canadian Coast Guard
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Railway Transport – Transport Ferroviaire

Chief, Compliance and
Dangerous Goods Coordinator –
Eastern Canada
Operations Branch
Railway Transport Committee
Canadian Transport Commission
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Western Canada and Chief, Operations
Railway Transport Committee
Canadian Transport Commission
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Chief, Equipment & Dangerous Commodities
Railway Transport Committee
Canadian Transport Commission
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Winnipeg, **MANITOBA**
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949-7299

Chief, Dangerous Commodities
Railway Transport Committee
Canadian Transport Commission
20 Toronto Street, 5th Floor
Toronto, **ONTARIO**
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Équipement et installations de
matière dangereuses
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Explosives – Explosifs

Chief Inspector of Explosives and Director
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OTTAWA, Ontario
K1A 0N6
Telephone: (613) 957-6787
Telex: 053-3128

Ports – Ports

Senior Advisor
Technical Services Branch
Ports Canada
99 Metcalfe Street, 8th Floor
OTTAWA, Ontario
K1A 0N6
Telephone: (613) 957-6787
Telex: 053-4127

Manager, Operations
Prince Rupert Port Corporation
110-3rd Avenue West
PRINCE RUPERT, British Columbia
V8J 1K8
Telephone: (604) 627-7545
Telex: 047-89192

Harbour Master
Vancouver Port Corporation
1900-200 Granville Street
VANCOUVER, British Columbia
V6C 2P9
Telephone: (604) 666-2405
Telex: 04-55484

Surveillant des quais
Ports Canada
Port de Sept-Îles
Case postale 280
SEPT-ILES (Québec)
G4R 4K5
Téléphone: (418) 968-1231
Télex: 051-8-4209

Surintendant des terminus
Port de Trois-Rivières
1545 du Fleuve
Case postale 999
TROIS-RIVIÈRES (Québec)
G9A 5K2
Téléphone: (819) 378-2887
Télex: 05-837226

Capt de port adjoint ou agent
Prévention des incendies et sinistres
Édifice du port de Montréal
Aile n°2, 3ième étage
Cité du Havre
MONTRÉAL (Québec)
H3C 3R5
Téléphone: (514) 283-7026
Télex: 05-267678

Agent de prévention
Port de Québec
271 De L'estuaire
Case postale 2268
QUÉBEC (Québec)
G1K 7P7
Téléphone: (418) 648-3896
Télex: 051-2297

Ass't. Harbour Master and
E.P.L.O.
Saint John Port Corporation
133 Prince William Street
P.O. Box 6429 Station A
SAINT JOHN, New Brunswick
E2L 4R8
Telephone: (506) 648-4883 or 648-4884
or
648-4843
Telex: 01447281

Director Operations & Harbours Master or
Ass't. Harbour Master or Environmental Officer
Operations Department
Port of Halifax
Terminal Road
P.O. Box 336
HALIFAX, Nova Scotia
B3J 2P6
Telephone: (902) 426-3648
or
426-3115
Telex: 019-21643

Harbour Master
Port of St. John's
P.O. Box 6178
ST. JOHN'S, Newfoundland
A1C 5X8
Telephone: (709) 772-4667
Telex: 016-3343

St. Lawrence Seaway – Voie maritime du Saint-Laurent

Director/Chief Marine Section
The St. Lawrence Seaway Authority
Operations and Maintenance Branch
202 Pitt Street
Cornwall, **ONTARIO**
K6J 3P7
Telephone: (613) 932-5170
Telex: 05-811517

Part II — Provincial Regulatory Agencies

Partie II — Organismes provinciaux de réglementation

Road Transport – Transport routier

Director, Administration and Road Safety
Motor Vehicle Department
Ministry of Transportation and Highways
2631 Douglas Street
Victoria, **BRITISH COLUMBIA**
V8T 5A3
Telephone: (604) 387-3142 or 387-5585
Telex: 049-7273

Executive Director
Dangerous Goods Control
Public Safety Services
10320-146th Street
Edmonton, **ALBERTA**
T5N 3A2
Telephone: (403) 422-9600
Telex: 037-41791

(ALBERTA will also do Consignors, Manufacturers, Consignees, etc.)
(L'Alberta s'occupera également des expéditeurs, fabricants, destinataires, etc.)

Dangerous Goods Officer
Transport Services Branch
Saskatchewan Highways and Transportation
2260-11th Avenue, 12th Floor
Regina, **SASKATCHEWAN**
S4P 3V5
Telephone: (306) 787-5527

Dangerous Goods Handling and Transportation Information
Environmental Management Division
Department of Environment, Workplace Safety & Health
Bldg. 2, 139 Tuxedo Avenue
Winnipeg, **MANITOBA**
R3N 0H6
Telephone: (204) 945-7094
Telex: 07-587589

Manager, Operational Policy and Standards Office
Ontario Ministry of Transportation and Communications
Room 212, West Building
1201 Wilson Avenue
Downsview, **ONTARIO**
M3M 1J8
Telephone: (416) 235-3568 or 235-3569

Direction du transport routier des marchandises
Ministère des Transports
700 est, St-Cyrille — 22e étage
Québec **(QUÉBEC)**
G1R 5H1
Téléphone: (418) 643-2235
Télex: 051-3733

Registrar of Motor Vehicles
Motor Vehicle Division
Department of Transportation
Kings Place, York Tower
York Street
P.O. Box 6000
Fredericton, **NEW BRUNSWICK**
E3B 5H1
Telephone: (506) 453-2407
Telex: 014-46230

Supervisor or Director
Motor Vehicle Inspection Division
Road Transport Inspection Section
Department of Transportation
6061 Young Street
P.O. Box 156
Halifax, **NOVA SCOTIA**
B3J 2M4
Telephone: (902) 424-4335
Telex: 019-22866

Manager Equipment Support
Department of Transportation
P.O. Box 4750
St. John's, **NEWFOUNDLAND**
A1C 5T7
Telephone: (709) 576-3288
Telex: 016-3101

Director
Highway Safety Division
Transportation and Public Works
17 Haviland Street
P.O. Box 2000
Charlottetown, **PRINCE EDWARD ISLAND**
C1A 7N8
Telephone: (902) 566-2474
Telex: 014-44154

Manager Environmental Services
Pollution Control Division
Department of Renewable Resources
Government of the Northwest Territories
P.O. Box 1320
Yellowknife, **NORTHWEST TERRITORIES**
X1A 2L9
Telephone: (403) 873-7654
Telex: 034-455 28

Transportation of Dangerous Goods
Coordinator
Department of Community &
Transportation Services
P.O. Box 2703
Whitehorse, **YUKON**
Y1A 2C6
Telephone: (403) 667-3032
Telex: 036-8-250

Hazardous Wastes – Déchets dangereux

Environmental Safety Program Officer
Waste Management Branch
Ministry of the Environment
Parliament Buildings
810 Blanshard Street
Victoria, **BRITISH COLUMBIA**
V8V 1X5
Telephone: (604) 387-9955

Branch Head
Pollution Control Division
Waste Management Branch
Alberta Environment
Oxbridge Place
9820-106th Street
Edmonton, **ALBERTA**
T5K 2J6
Telephone: (403) 427-5868

Director, Land Protection Branch
Saskatchewan Environment
Walter Scott Building
3085 Albert Street
Regina, **SASKATCHEWAN**
S4S 0B1
Telephone: (306) 787-6183

Dangerous Goods Handling and
Transportation Information
Environmental Management Division
Department of Environment,
Workplace Safety & Health
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Winnipeg, **MANITOBA**
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Industrial Waste Management Unit
Waste Management Branch
Ontario Ministry of the Environment
40 St. Clair Avenue West, 5th Floor
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M4V 1M2
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Directeur des substances dangereuses
Direction générale du Milieu terrestre
Ministère de l'Environnement
3900, rue Marly
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G1X 4E4
Téléphone: (418) 643-3794

Hazardous Waste Officer
Pollution Control Branch
Environment New Brunswick
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P.O. Box 6000
Fredericton, **NEW BRUNSWICK**
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Telex: 014-46230

Environmental Engineer
Environmental Assessment Division
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5151 Terminal Road
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Environmental Investigations Division
Department of the Environment
West Block, 4th Floor
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Chief, Air and Solid Waste Management Section
Environmental & Technical Services Unit
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Manager Environmental Services
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Telex: 036 8 260

APPENDIX 7

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